Corrosion

Official Publication
NATIONAL ASSOCIATION OF CORROSION ENGINEERS

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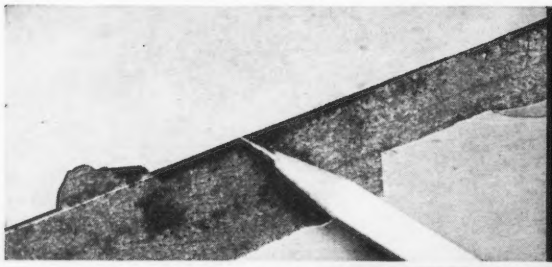
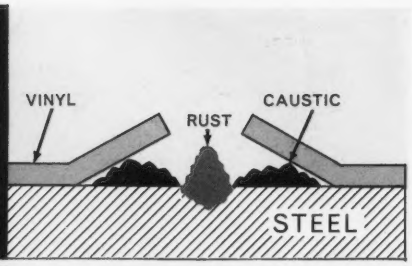
VOL. 14 JULY, 1958 NO. 7

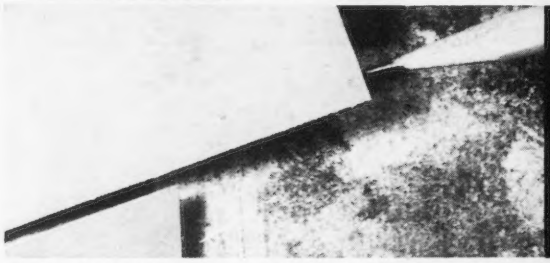
PUZZLED ABOUT PRIMERS?

Here are tests you can duplicate

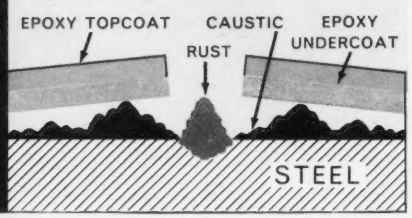


TEST 1—One coat of self-priming vinyl. Coating breaks away (L) due to severe undercutting (R), exposing metal to progressive corrosion.

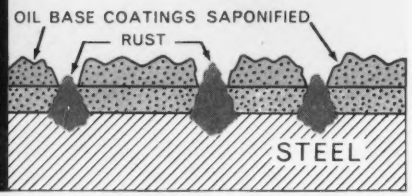




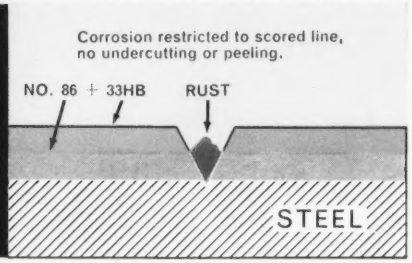
TEST 2—Epoxy primer, epoxy topcoat. Coating lifts off in single sheet (L) as adhesion fails (R), exposing entire surface to corrosion.



TEST 3—Oil primer, oil topcoat. Both coats fail completely (L) as underfilm caustic reacts on their oils to form soaps (R).



TEST 4—Amercoat's No. 86 inhibitive primer and No. 33HB vinyl topcoat. Corrosion restricted to scored line (L), no undercutting or peeling (R).



The purpose of these accelerated tests is to show what happens when various types of coatings are exposed to a typical corrosive environment. Four clean steel panels, free from mill scale and rust, were coated with different combinations of primers and topcoats. Each was scribed to bare metal and immersed in salt water in the presence of free oxygen, for two weeks.

As caustic deposits formed over cathodic areas of the steel in tests 1, 2 and 3, failure occurred in three ways. The vinyl, though not directly attacked, was undercut as caustic spread beneath the film and destroyed adhesion. The epoxy coating, known for critical adhesion to smooth metal, proved impervious to caustic attack. It was, however, lifted in its entirety as moisture spread beneath the surface. The entire oil paint film was quickly penetrated by the salt solution, creating widespread corrosion and caustic formation. The caustic then reacted with the oil to saponify the film.

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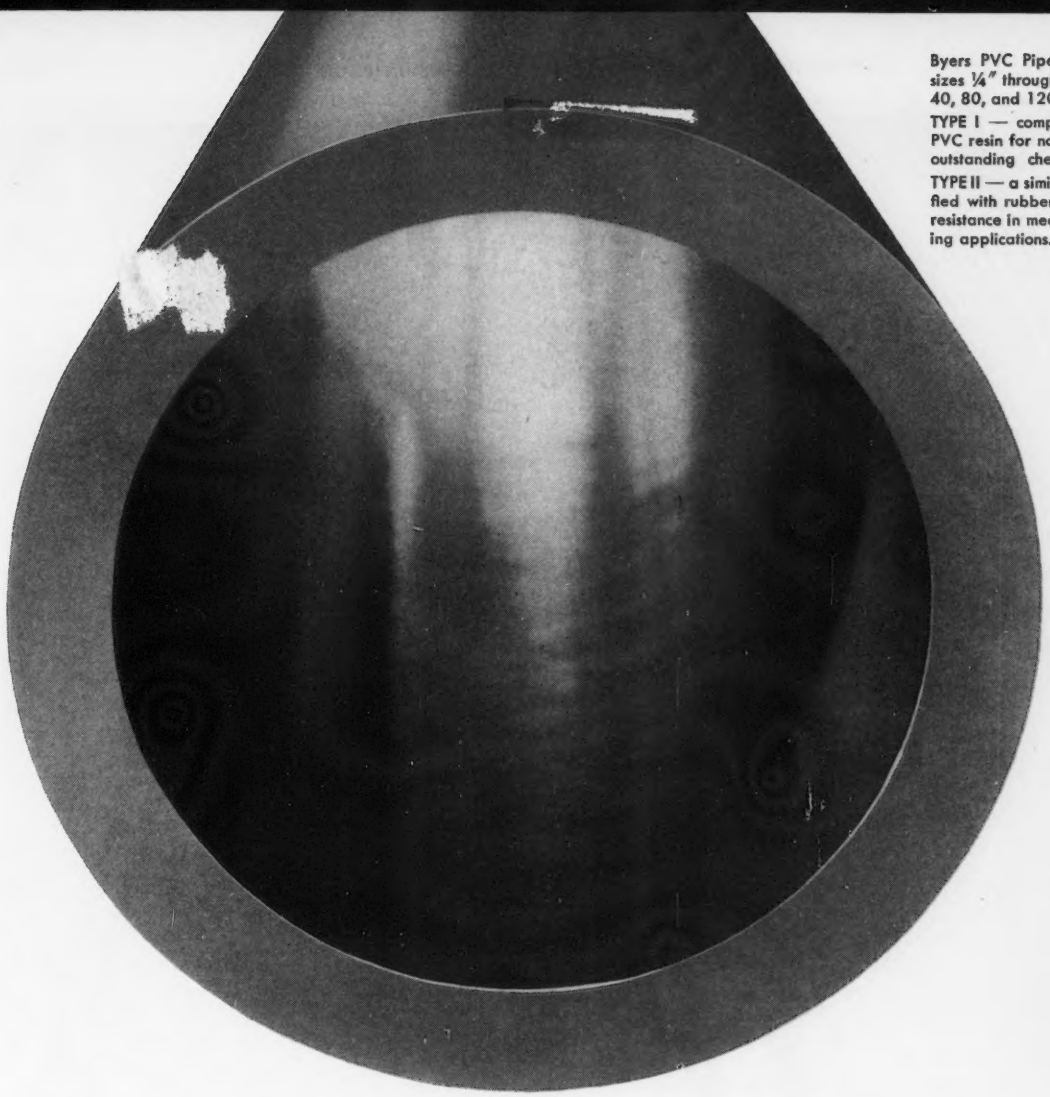

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devoted entirely to corrosion research and control

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TECHNICAL COMMITTEE REPORT SCHEDULED FOR AUGUST

Present Status of the Oil Ash Corrosion Problem. A Progress Report of NACE Task Group T-5B-3 on Oil Ash Corrosion, R. T. Foley, General Electric Co., Schenectady, chairman.

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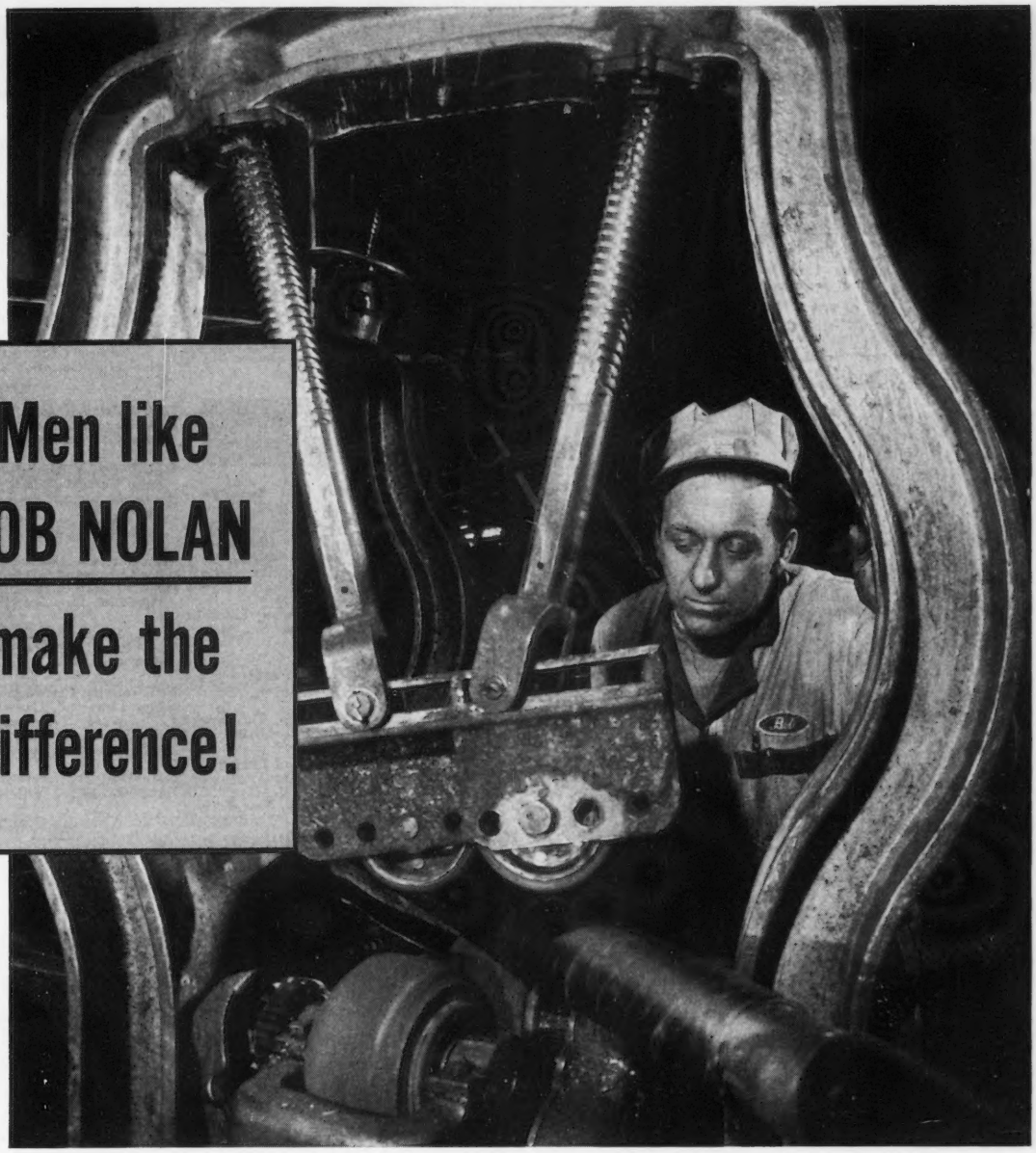

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T-2J Wrappers for Underground Pipe Line Coating
Clark A. Bailey, Chairman; Johns-Manville Sales Corp., 22 East 40th St., New York 16, N. Y.

T-2J-1 Asbestos Felt
W. T. Ferrell, Chairman; Philip Carey Co., Special Industries Dept., Lockland, Cincinnati 15, Ohio

T-2J-2 Glass Wrap
E. J. Pennell, Chairman; Owens-Corning Fiberglas Corp., 902 American Airlines Bldg., Tulsa, Okla.

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UNICHROME
Trade Mark

News about
COATINGS for METALS
Metallic.....Organic.....Decorative.....Protective

Improved phenolic linings extend tank life

Plastisol gives tank exteriors "lifetime" protection

Serious tank corrosion often occurs from the outside in. Solution spillage and corrosive atmospheres can deteriorate ordinary coatings and attack the metal, shorten equipment life.

ELIMINATES MAINTENANCE

Protecting the exterior of tanks and equipment with Unichrome "Super 5300" Plastisol is good practice, good economy. Especially so where maintenance is difficult. For this same material that is protecting so many tank *interiors* makes *exteriors* corrosion resistant, too. One application usually gives lifetime protection. Non-porous and seamless, this vinyl shield stops corrosive fluids and fumes.

CAN BE PATCHED

Its flexibility and toughness help prevent impact and abrasion damage. Should patching ever become necessary, Unichrome "Super 5300" can be sprayed on, spot baked, and protection restored good as ever.

See details in your copy of "CEC", or send for Bulletin Chem C-3.

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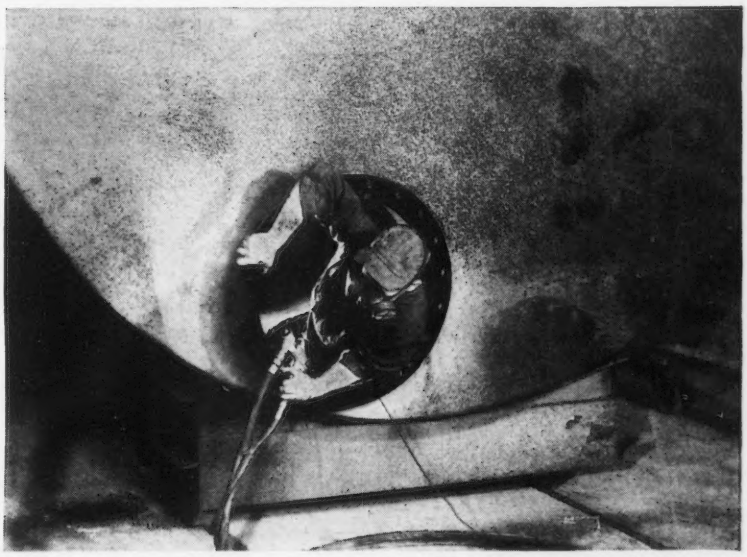

Specialists are located in key areas to apply Unichrome Phenolic Linings. They have the experience and the facilities to handle even large, difficult jobs promptly and properly.
Photo Courtesy General Coating Co., Woodbridge, N.J.

Unichrome B-124 Linings have increased resistance to impact, give thicker films, positive cure-control

Phenolic coatings continue to provide a most economical lining for tanks, tank cars, drums. Features have been incorporated into the Unichrome Series B-124 phenolics that greatly improve the physical properties...increasing their reliability still further for corrosive service.

WON'T CHIP ON IMPACT

Improved reverse impact resistance of Unichrome phenolic linings is especially valuable in containers and tanks subject to handling abuses. Linings stick tight, prevent exposure of metal, guard against corrosion and contamination of the product.

SPECIAL FEATURES

Unichrome Series B-124 Linings include materials that bake to a hard, glossy surface for an easy-to-clean final coat; others go on as thick as two mils per coat — twice that of ordinary phenolics; still another signals with a visible color change when fully cured, to assure optimum durability.

Unichrome B-124 Coatings stand up in direct contact with wide range of active materials, including strong acids and solvents. Write Metal & Thermit for information and names of nearby applicators that can give you fast service even on large equipment.

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(Continued From Page 6)

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F. B. Burns, Chairman; Kerr-McGee Oil Industries, Inc., Box 305, Wynnewood, Okla.

T-2J-4 Rag Felt
L. S. Parker, Chairman; Pabco Industries, 475 Brannan St., San Francisco, Calif.

T-2J-5 Rock Shield
W. T. Ferrell, Chairman; Philip Carey Mfg. Co., Lockland, Cincinnati 15, Ohio

T-2K Prefabricated Plastic Film for Pipe Line Coating
J. J. Wise, Chairman; Arkansas-Louisiana Gas Co., Box 1734, Shreveport, La.
H. D. Segool, Vice Chairman; The Kendall Co., Polyken Sales Division, 309 West Jackson Blvd., Chicago, Ill.

T-2K-1 Standards
H. D. Segool, Chairman; Kendall Co., Polyken Sales Div., 309 W. Jackson Blvd., Chicago, Ill.

T-2K-2 Research and Development
H. A. Hendrickson, Chairman; Minnesota Mining & Mfg. Co., 900 Fauquier St., St. Paul, Minn.

T-2K-3 History and Results
F. E. Costanzo, Chairman; Manufacturers Light & Heat Co., 800 Union Trust Bldg., Pittsburgh, Pa.

T-2L Wax-Type Pipe Coatings and Component Wrappers
J. O. Mandley, Chairman; Michigan Consolidated Gas Co., 415 Clifford, Detroit 26, Mich.
I. E. Davis, Vice Chairman; 2140 Bethel Road, Columbus 21, Ohio

T3 General

A. H. Roebuck, Chairman; The Western Co., Midland Tower Bldg., P. O. Box 310, Midland, Texas

T-3A Corrosion Inhibitors
S.K. Coburn, Chairman; Association of American Railroads, 3140 South Federal St., Chicago, Ill.
L. C. Rowe, Vice Chairman; Research Staff, General Motors Corp., Box 188, North End Station, Detroit 2, Mich.

T-3A-1 General Theory of the Action of Corrosion Inhibitors
W. W. Sweet, Chairman; Research & Development Dept., Colgate Palmolive Co., 105 Hudson St., Jersey City, N. J.

T-3A-2 Methods of Testing & Screening Corrosion Inhibitors
(Chairman to be Selected)

T-3A-3 Materials Available for and Application of Corrosion Inhibitors
Lyle A. Timm, Chairman; 8450 Ferry Road, Gross Ile, Michigan

T-3B Corrosion Products
A. H. Roebuck, Chairman; The Western Co., Midland Tower Bldg., P. O. Box 310, Midland, Texas
D. A. Vaughan, Vice Chairman, Battelle Memorial Institute, 505 King Avenue, Columbus, Ohio.

T-3C Annual Losses Due to Corrosion
S. K. Coburn, Chairman, Association of American Railroads, 3140 South Federal Street, Chicago 16, Illinois

T-3D Instruments for Measuring Corrosion
E. H. Thalmann, Chairman; Ebasco Services, Inc., 2 Rector St., New York, N. Y.
F. W. Ringer, Vice Chairman; 7 Hampden Ave., Narberth, Pa.

T-3D-1 Electrical Holiday Inspection of Coatings
W. A. Broome, Chairman; Arkansas-Louisiana Gas Co., Box 1734, Shreveport, La.

T-3E Railroads
L. J. Nicholas, Chairman; The Pullman Co., Engineer of Research, Room 5-40, Merchandise Mart Plaza, Chicago, Ill.
G. M. Magee, Vice Chairman, Assoc. American Railroads, 3140 South Federal Street, Chicago, Ill.

T-3E-1 Corrosion of Railroad Tank Cars
J. R. Spraul, Chairman; General American Transportation Corp., 150 West 151st Street, East Chicago, Ind.
C. M. Jekot, Vice Chairman; DeSoto Paint & Varnish Co., P. O. Box 186, Garland, Texas.
L. R. Honnaker, Vice Chairman, Engineering Materials Group, Eng. Dept., E. I. du Pont de Nemours & Co., Inc., 13W15 Louviers Bldg., Wilmington, Del.

T-3E-2 Corrosion in Railroad Hopper Cars
C. L. Crockett, Chairman; Norfolk and Western Railway, Motive Power Dept., Roanoke, Va.

T-3F Corrosion by High Purity Water
R. U. Blaser, Chairman; Research Center, Babcock & Wilcox Co., Box 835, Alliance, Ohio.
M. C. Bloom, Vice Chairman; Metallurgy Div., Naval Research Lab., Washington, D. C.

T-3F-2 Inhibitors
R. C. Ulmer, Chairman, Combustion Engineering Co., 200 Madison Avenue, New York, N. Y.

T-3F-3 Corrosion Products
W. L. Pearl, Chairman, General Electric Company, Atomic Power Equipment Dept., Box 254, San Jose, Calif.

T-3F-6 Intercommittee Activities
E. P. Partridge, Chairman, Hall Labs., Box 1346, Pittsburgh, Pa.

T-3F-7 Bibliography
W. K. Boyd, Chairman; Battelle Memorial Institute, 505 King Ave., Columbus, Ohio

T-3G Cathodic Protection
Dr. T. P. May, International Nickel Co., Inc., P. O. Box 262, Wrightsville Beach, North Carolina

T-3G-1 Cathodic Protection of Hull Bottoms of Ships
L. P. Sudrabin, Chairman, Electro Rust-Proofing Corp., Box 178, Newark, New Jersey.

T-3G-2 Cathodic Protection of Heat Exchangers
R. B. Teel, Chairman, The International Nickel Co., Inc., Box 262, Wrightsville Beach, N. C.

T-3G-3 Cathodic Protection of Process Equipment
A. A. Brouwer, Chairman, The Dow Chemical Co., Midland, Michigan.

T-3H Tanker Corrosion
W. S. Quimby, Chairman; Res. & Tech. Dept., The Texas Company, Box 509, Beacon, New York.

T4 Utilities

Daniel R. Werner, Chairman; American Tel. & Tel. Co., Room 1701, 324 East 11th St., Kansas City 6, Mo.

T-4A Effects of Electrical Grounding on Corrosion
T. R. Stilley, Chairman; Good-All Electric Mfg. Co., Good-All Bldg., Ogallala, Neb.
O. W. Zastrow, Vice Chairman; Electric Engineering Div., Rural Electrification Adm., U.S.D.A., Washington 25, D. C.

T-4A-3 Methods and Materials for Grounding
I. C. Dietze, Chairman; Dept. of Water & Power, Box 3669, Terminal Annex, Los Angeles 54, Cal.

T-4B Corrosion of Cable Sheaths
T. J. Maitland, Chairman, American Telephone & Telegraph Co., 32 Avenue of the Americas, New York, N. Y.
H. M. Clayton, Vice Chairman; Memphis Gas, Light and Water Div., Box 388, Memphis, Tenn.

T-4B-1 Lead and Other Metallic Sheaths
T. J. Maitland, Chairman, American Telephone & Telegraph Co., 32 Avenue of the Americas, New York 13, New York.

T-4B-2 Cathodic Protection
J. J. Pokorny, Chairman, Cleveland Elec. Illuminating Co., 75 Public Sq., Cleveland 1, Ohio.

T-4B-3 Tests and Surveys
D. R. Werner, Chairman, American Telephone & Telegraph Co., 324 East 11th Street, Room 1701, Kansas City, Mo.
H. M. Clayton, Vice Chairman, Memphis Gas, Light and Water Div., Box 388, Memphis, Tenn.

T-4B-4 Protection of Pipe Type Cables
H. W. Dieck, Chairman, Long Island Lighting Company, 175 Old Country Road, Hicksville, New York.
J. B. Prime, Jr., Vice Chairman, Florida Power & Light Co., Box 3100, Miami, Florida.

T-4B-5 Non-Metallic Sheaths and Coatings
C. L. Mercer, Chairman; Southwestern Bell Tel. Co., Box 58, Westfield, Texas

T-4B-6 Stray Current Electrolysis
J. Svetlik, Chairman, Northern Indiana Public Service Co., 5265 Hohman Ave., Hammond, Indiana.
G. H. Cantwell, Vice Chairman, Indiana Bell Telephone Co., 240 N. Meridian St., Indianapolis, Indiana.

T-4D Corrosion by Deicing Salts
W. H. Bruckner, Chairman; University of Illinois, Urbana, Illinois.
K. G. Compton, Vice Chairman; Bell Telephone Laboratories, Murray Hill, New Jersey.

T-4D-1 Procedures for Conducting Field Tests Below Ground
F. E. Kulman, Chairman, Consolidated Edison Co. of New York, Inc., 4 Irving Place, New York, N. Y.

T-4D-2 Coordination of Field Programs Between Cities and Transportation Companies
George Illig, Chairman, Calgon, Inc., 323 Fourth Ave., Pittsburgh, Penn.

T-4E Corrosion by Domestic Waters
T. E. Larson, Chairman, Illinois State Water Survey, Box 232, Urbana, Illinois.
J. F. J. Thomas, Vice Chairman, Industrial Water Section; Dept. of Mines & Tech. Surveys; 40 Lydia Street, Ottawa, Ontario, Canada

T-4E-1 Hot Water Tank Corrosion
R. C. Weast, Chairman; Associate Professor of Chemistry, Case Institute of Technology, University Circle, Cleveland 6, Ohio.

T-4F Materials Selection for Corrosion Mitigation in the Utility Industry
F. E. Kulman, Temporary Chairman, Consolidated Edison Co. of New York, Inc., 4 Irving Place, New York, N. Y.

T-4F-1 Materials Selection in the Water Industry
Daniel Cushing, Chairman, 148 State St., Boston, Massachusetts.
Chester Anderson, Vice Chairman; Crane Company, 4100 South Kedzie Ave., Chicago 5, Ill.
Peter Kahn, Secretary; Metcalf & Eddy, 1300 Statler Bldg., Boston, Mass.

T-4F-2 Materials Selection in the Electric Industry

T5 Corrosion Problems in the Process Industries

R. I. Zimmerer, Chairman; Petro-Tex Chemical Corp., Box 2584, Houston, Texas.
C. P. Dillon, Vice Chairman; Union Carbide Chemicals Co., Div. of Union Carbide Corp., P. O. Box 2831, Charleston, W. Va.

T-5A Corrosion in Chemical Processes
C. P. Dillon, Chairman; Union Carbide Chemicals Co., Div. of Union Carbide Corp., P. O. Box 2831, Charleston, W. Va.
W. H. Burton, Vice-Chairman, General Chemical Division, Allied Chemical & Dye Corp., Camden 3, New Jersey

T-5A-1 Sulfuric Acid
W. A. Luce, Chairman, The Duriron Co., Box 1019, Dayton, Ohio.

T-5A-3 Acetic Acid
J. A. Manning, Jr., Chairman; Celanese Corp. of America, Box 1414, Charlotte, N. C.

T-5A-4 Chlorine
L. W. Gleekman, Chairman; Wyandotte Chemicals Corp., 1609 Biddle Ave., Wyandotte, Mich.

T-5A-5 Nitric Acid
N. D. Groves, Chairman; Apartment 33-B, Brookline Manor, Reading, Pa.
F. H. Meyer, Vice Chairman; National Lead Co. of Ohio, Box 158, Mt. Healthy Station, Cincinnati 31, Ohio.

T-5A-6 HF Corrosion
T. L. Hoffman, Chairman, Phillips Petroleum Co., Atomic Energy Div., Box 1259, Idaho Falls, Idaho.
F. H. Meyer, Jr., Vice Chairman; National Lead Co. of Ohio, Box 158, Mt. Healthy Station, Cincinnati 31, Ohio

T-5B High Temperature Corrosion
E. N. Skinner, Chairman; The International Nickel Co., Inc., 67 Wall St., New York, N. Y.
J. L. McPherson, Vice Chairman; 12230 So. Artesian Avenue, Blue Island, Ill.

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T-5C Corrosion by Cooling Waters

T-5C-1 Corrosion by Cooling Waters (South Central Region)

J. M. Brooke, Chairman; Phillips Petroleum Co., Sweeny Refinery, Sweeny, Texas

W. W. Wheeler, Secretary; Rohm & Haas, Box 672, Pasadena, Texas.

T-5D Plastic Materials of Construction

S. W. McIlrath, Chairman, 151 East 214th St., Euclid, Ohio.

R. E. Gackenbach, Vice-Chairman; American Cyanamid Co., Organic Chemical Div., Bound Brook, N. J.

T-5D-1 Questionnaires

S. W. McIlrath, Chairman, 151 E. 214th Street, Euclid 23, Ohio.

T-5D-2 Inorganic Acids

R. J. Collins, Secretary; B. F. Goodrich Chemical Co., 3135 Euclid Avenue, Cleveland 15, Ohio

T-5D-3 Inorganic Alkalies

Peter Kimen, Chairman, Champion Paper & Fibre Co., Box 872, Pasadena, Texas.

L. B. Connelly, Secretary, Eastman Chemical Products Company, 704 Texas National Bank Building, Houston 2, Texas.

T-5D-4 Gases

Beaumont Thomas, Chairman, Stebbins Eng. & Mfg. Co., Eastern Blvd., Watertown, New York.

J. L. Forse, Vice Chairman, Dow Chemical Company, Plastics Technical Service, Midland, Michigan.

William Eakins, Secretary; Chemical Corp., Pla-Tank Division, West Warren, Mass.

T-5D-5 Water and Salt Solutions

Paul Elliott, Chairman, Naugatuck Chemical Company, Kralastic Development, Naugatuck, Conn.

T-5D-6 Organic Chemicals

Wade Wolfe, Jr., Secretary, 73 Ermann Drive, Buffalo 17, New York.

T-5D-7 Engineering Design

O. H. Fenner, Chairman, Monsanto Chemical Company, 1700 South Second Street, St. Louis 4, Missouri.

K. A. Phillips, Vice-Chairman, American Zinc, Lead & Smelting Co., P. O. Box 495, East St. Louis, Illinois.

W. B. Meyer, Secretary, St. Louis Metallizing Co., 625 South Sarah, St. Louis 10, Missouri.

T-5D-8 Methods and Criteria for Evaluating Plastics in Chemical Environment

R. F. Clarkson, Chairman, Olin Mathieson Chemical Corp., Mathieson Building, Baltimore, Md.

R. Lembcke, Secretary, Cities Service Res. & Dev. Co., 920 East Third. Tulsa 3, Oklahoma.

T-5E Stress Corrosion Cracking of Austenitic Stainless Steel

L. Miller Rogers, Chairman; Union Carbide Chemicals Co., Box 471, Texas City, Texas.

E. V. Kunkel, Vice Chairman; Celanese Corp., Box 148, Bishop, Texas.

T6 Protective Coatings

L. S. Van Delinder, Chairman; Union Carbide Chemicals Co., Development Dept., South Charleston, W. Va.

O. H. Fenner, Vice-Chairman; Monsanto Chemical Co., 1700 South Second St., St. Louis 4, Mo.

T-6A Organic Coatings and Linings for Resistance to Chemical Corrosion

C. G. Munger, Chairman; Amercoat Corp., 4809 Firestone Blvd., South Gate, Cal.

L. S. Van Delinder, Vice Chairman; Union Carbide Chemicals Co., Development Dept., South Charleston, W. Va.

J. I. Richardson, Secretary; Amercoat Corp., 4809 Firestone Blvd., South Gate, Cal.

T-6A-1 Rubber Linings

R. McFarland, Jr., Chairman; Hills-McCanna Co., 400 Maple Street, Carpentersville, Illinois

T-6A-2 Vinyl Coatings

K. Tator, Chairman, 2020 Montour Street, Coraopolis, Pa.

T-6A-3 Vinylidene Chloride Polymers

R. L. Brown, Chairman, The Dow Chemical Co., Midland, Mich.

T-6A-4 Phenolics

Forest Baskett, Chairman; Sheet Metal Engineers, Inc., Box 9384, Houston 11, Texas

T-6A-5 Polyethylene

L. S. Van Delinder, Chairman, Carbide & Carbon Chemicals Co., South Charleston, W. Va.

T-6A-6 Neoprene

J. R. Galloway, Chairman; E. I. du Pont de Nemours & Co., Inc., 2601A West Grove Lane, Houston 6, Texas

T-6A-7 Thermosetting Coal Tar Coatings

Woodrow E. Kemp, Chairman; Koppers Co., Inc., 15 Plum Street, Verona, Pa.

T-6A-8 Methacrylates

T-6A-9 Furanes

T-6A-10 Polyesters

D. D. Cone, Chairman; c/o Sunrise Coffee Shop, 118 East Texas, Baytown, Texas

T-6A-11 Epoxys

C. G. Munger, Chairman, Amercoat Corp., 4809 Firestone Blvd., South Gate, Cal.

T-6A-12 Fluorocarbons

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T-6A-14 Organic-Brick Covered

Ronald C. Flynn, Chairman; Stebbins Manufacturing Co., 363 Eastern Blvd., Watertown, N. Y.

T-6A-15 Rigid Vinyls

C. G. Munger, Chairman; Amercoat Corp., 4809 Firestone Blvd., Southgate, Calif.

T-6A-16 Coal Tar Coatings

T-6A-17 Polyurethanes

Richard Sansone, Chairman; Mobay Chemical Company, 1815 Washington Road, St. Louis 4, Mo.

T-6A-18 Hypalon

J. R. Galloway, Chairman; E. I. du Pont de Nemours & Co., Inc., 2601A West Grove Lane, Houston 6, Texas

T-6A-19 Asphalts

T-6A-20 Plastisols

O. H. Fenner, Chairman; Monsanto Chemical Co., 1700 South Second St., St. Louis 4, Mo.

T-6B Protective Coatings for Resistance to Atmospheric Corrosion

Howard C. Dick, Chairman, Products Research Service, Inc., Box 6116, New Orleans.

T-6B-1 Linseed and Other Drying Oils

T-6B-2 Ester Gum Oil

R. L. Liston, Chairman, Cook Paint & Varnish Co., Box 3088, Houston, Tex.

T-6B-3 Straight Phenolic Oil Varnish

John W. Nee, Chairman, Briner Paint Mfg. Co., 3713 Agnes St., Corpus Christi, Texas.

T-6B-4 Modified Phenolic Oil Varnish

John W. Nee, Chairman.

T-6B-5 Straight Alkyd Varnish

T-6B-6 Modified Alkyd Varnish

T-6B-7 Epoxy Esters

T-6B-8 Epoxy (Amine Cured)

Earl Gould, Chairman, Continental Oil Co., Harvey, La.

T-6B-9 Chlorinated Rubber

Otto Grosz, Chairman, The California Co., Box 128, Harvey, La.

T-6B-10 Vinyls

John I. Richardson, Chairman; Amercoat Corporation, 4809 Firestone Blvd., South Gate, Cal.

T-6B-11 Metallic Silicates

T-6B-12 Coal Tar

M. Mitchell, Chairman, Reilly Tar & Chem. Co., 1616 Merchants Bank Bldg., Indianapolis, Ind.

T-6B-13 Asphalt

C. C. Allen, Chairman, Anderson-Pritchard Oil Co., 1000 Liberty Bank Bldg., Oklahoma City, Okla.

T-6B-14 New Developments

Joe Rench, Chairman, Napko Corp., Box 14126, Houston, Tex.

T-6B-15 Silicones

W. F. Gross, Chairman; c/o Norton Jaggard, Manager Engineering, Arabian American Oil Co., 505 Park Ave., New York 22, N. Y.

T-6C Protective Coatings for Resistance to Marine Corrosion

John F. Oliveira, Chairman; Bethlehem Steel Co., Shipbuilding Div., Bethlehem Sparrows Point Shipyard, Sparrows Point 19, Md.

T-6D Industrial Maintenance Painting

R. H. Bacon, Chairman; Dow Chemical Co., Maintenance Shops, Freeport, Texas

C. R. Martinson, Vice Chairman; Monsanto Chemical Company, 1700 South Second Street, St. Louis, Mo.

T-6D-1 Economics of Maintenance Painting

S. L. Lopata, Chairman, Carboline Co., 331 Thornton Ave., St. Louis, Mo.

T-6D-2 Standardization of Scope of Painting Specifications

L. L. Sline, Chairman, Sline Industrial Painters, 2162 Gulf Terminal Dr., Houston, Tex.

T-6D-3 Paint Programs

R. H. Bacon, Chairman, The Dow Chemical Co., Freeport, Tex.

T-6E Protective Coatings in Petroleum Production

C. G. Fritts, Chairman; Socony Paint Products Co., Box 1740, Houston, Texas.

F. E. Blount, Vice Chairman; Magnolia Petroleum Co., Box 900, Dallas, Texas.

T-6F Protective Interior Linings, Application and Methods

W. P. Cathcart, Chairman, Tank Lining Corporation, 246 Washington Road, Pittsburgh, Pennsylvania.

A. R. Gabel, Vice-Chairman; The Dow Chemical Co., Midland, Mich.

J. H. Cogshall, Secretary; Pennsalt Mfg. Co., 3 Penn Center, Philadelphia, Pa.

T-6F-1 Curing

K. G. Lefevre, Chairman; Metalweld, Inc., 2617 Hunting Park Ave., Philadelphia, Pa.

T-6F-2 Surface Preparation

L. R. Mangram, Chairman; Linco, Inc., 6735 Avenue W, Houston, Texas.

T-6F-3 Inspection

J. L. Barker, Chairman; Union Carbide Chemicals Co., Div. of Union Carbide Corp., P. O. Box 8004, Bldg., 82-421, South Charleston 3, W. Va.

T-6F-4 Safety

J. L. Barker, Temporary Chairman; Union Carbide Chemicals Co., Div. of Union Carbide Corp., P. O. Box 8004, Bldg. 82-421, South Charleston 3, W. Va.

T-6F-5 Application

H. Foelsch, Chairman; 20 Wistar Avenue, Metuchen, New Jersey

T-6G Surface Preparation for Organic Coatings

Joseph Bigos, Temporary Chairman; United States Steel Corp., Applied Research Lab., Monroeville, Pa.

T-6H Glass Linings and Vitreous Enamels

Ernest F. Meier, Chairman; Glascote Products, Inc., 20900 St. Clair Avenue, Cleveland 17, Ohio

R. McFarland, Jr., Vice Chairman; Hills-McCanna Co., 400 Maple Street, Carpentersville, Illinois

T-6J Protective Coating Application Problems

T-6J Los Angeles Area, Protective Coating Application Problems

Fred M. McConnell, Chairman, Service Coatings Corp., P. O. Box 524, Wilmington, Cal.

Newell W. Tune, Vice-Chairman, L. A. Water & Power, 510 East Second St., Los Angeles, Cal.

W. M. Jakway, Secretary, Bechtel Corporation, P. O. Box 58424, Los Angeles 58, Cal.

Paul C. Briley, Assistant Secretary, National Lead Co., 3113 East 26th St., Los Angeles, Cal.

T-6J-1 Specification Writing

Newell Tune, Chairman, Dept. of Water & Power, 510 East Second St., Los Angeles, Calif.

T-6J-2 Application Procedure

J. E. Lacy, Chairman, Barrett Div., Allied Chem. & Dye Corp., 923 East 3rd St., Los Angeles, Calif.

T-6J-3 Inspection Techniques

Miss Flora L. Davis, Chairman; Hughes Aircraft, Bldg. #20, Mail Station 1309, Florence and Teale, Culver City, California

T-6J-4 Cost Evaluation

T. Doyle, Chairman, Furane Plastics, 4516 Brazil St., Los Angeles, Calif.

T-6K Corrosion Resistant Construction With Masonry and Allied Materials

L. R. Honnaker, Chairman; E. I. du Pont de Nemours & Co., Inc., Eng. Dept., 33F.20 Louviers Bldg., Wilmington, Del.

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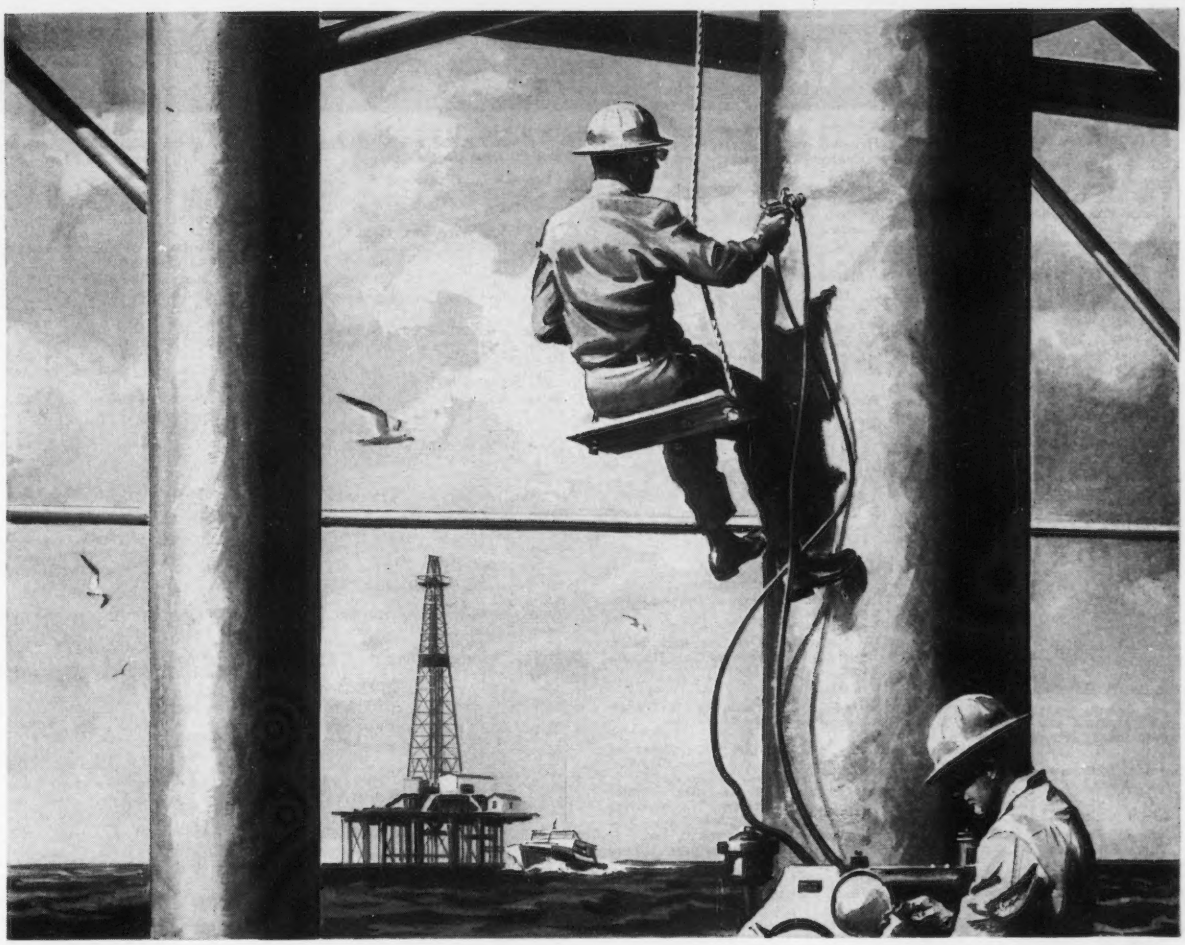

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T-6R Protective Coatings Research

J. H. Cogshall, Chairman; Pennsalt Chemical Corp., 3 Penn Center Plaza, Philadelphia, Pa.

T7 Corrosion Coordinating Committee

C. A. Erickson, Jr., Chairman; The Peoples Natural Gas Co., Two Gateway Center, Pittsburgh 22, Pa.

C. L. Mercer, Vice Chairman; Southwestern Bell Telephone Co., P. O. Box 58, Westfield, Texas.

T-7A Northeast Region Corrosion Coordinating Committee

C. A. Erickson, Jr., Chairman; The Peoples Natural Gas Co., Two Gateway Center, Pittsburgh 22, Pa.

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Chicago Area Committee on Underground Corrosion

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C. H. Bope, Secretary, Columbus & Southern Ohio Electric Co., 215 North Front St., Columbus 15, Ohio

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John L. Gray, Vice-Chairman, Louisville Gas & Electric Co., Louisville, Ky.

Walter Zell, Secretary, Louisville Gas & Electric Co., Louisville, Ky.

T-7D South Central Region Corrosion Coordinating Committee

C. L. Mercer, Chairman; Southwestern Bell Tel. Co., Box 58, Westfield, Texas

C. L. Woody, Vice Chairman, United Gas Corporation, Box 2628, Houston, Texas

Houston Corrosion Coordinating Committee

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O. W. Wade, Vice Chairman; World Supply Co., Suite 807, 3400 Montrose Blvd., Houston, Texas

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T-7E Western Region Corrosion Coordinating Committee

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T-9A Biological

Charles E. Lane, Chairman; Marine Laboratory, University of Miami, Coral Gables 34, Fla.

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T. R. Sweeney, Chairman, U. S. Naval Research Lab., Code 6120, Washington, D. C.

T-9D Correlation of Evaluation of Preservatives

Walter Bejuki, Chairman; National Academy of Sciences, National Research Council, 2101 Constitution Ave., Washington 25, D. C.

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NATION ENDORSES

ittsburgh Firm nnounces New letal Discovery

'ITTSBURGH (AP) — A. M. Byers put on the market today a new d of wrought iron described as most significant development in history of the metal.

This description was given at a vs conference yesterday by B. M. ers, president of the Pittsburgh n. It is the world's largest maker wrought iron products.

The improved product, known as D wrought iron, is at least 25 per nt more resistant to corrosion

Firm Producing Corrosion-Proof Wrought Iron

A new 4-D wrought iron has been announced by the A. M. Byers Co., Pittsburgh, according to E. G. Sullivan, field service engineer here for the firm.

Byers, largest producer of wrought iron, claims the new iron has greatly superior resistance against many kinds of corrosive forces, including

lew Wrought ron Produced

A new 4-D wrought iron" h 25 per cent increased rosion resistance has been ought out of the laboratory into production by the M. Byers Co., William E. eber of Seattle, Byers field rvice engineer, said Sunday. Weber said 4D wrought on is immediately available

4-D PIPE — R. R. Kirkwood (left), Chief Mechanical Engineer for John Graham & Company, Seattle, checks piece of 4-D Wrought Iron Pipe now being produced by A. M. Byers Co. Looking on is Byers' Seattle Field Service Engineer, W. E. Weber.

A. M. Byers Claims Improved Wrought Iro Less Likely to Corrode

By a WALL STREET JOURNAL Staff Reporter

PITTSBURGH—A. M. Byers Co., a prod of wrought iron products, announced its m lurgists have come up with a new and proved version of standard wrought iron.

Called 4-D wrought iron, simply a market term used to distinguish it from the stand product, it is expected to "aid substantia in reducing losses stemming from mate failures caused by corrosion, B. M. Mye president, stated.

He said that standard wrought iron is ready "a bulwark in the fight against cor sion." Wrought iron pipe, for instance, is us in water, waste and drainage lines, locomoti and diesel engine piping and underground a plane fueling lines, while flat rolled produc go into coal chutes, bridge decking, pier pr tection plates, structural members and proce materials tanks.

A. S. Chalfant, vice president-sales, said t new product will go on the market immed ately. He added that the new product will se for the same prices as those for standar wrought iron.

A. M. Byers Announces Results Of Tests On New 4-D Wrought Iron

PITTSBURGH, Mar. 18. — Results of three tests new 4-D wrought iron have been announced by the etallurgical department of A. M. Byers Company, ttsburgh. The test data documents the announcement made by A. S. Chalfant, vice president of sales, a press conference in ttsburgh in February at new 4-D wrought iron at least 25% more corgion is characterized by agitation and plentiful oxygen."

Test Conditions

Byers Improves Its Wrought Iron

Special to World-Telegram and Sun.

PITTSBURGH, Feb. 13.—A. M. Byers Co., producers of wrought iron products, announced its metallurgists have found a new and improved version of standard wrought iron.

Called 4-D wrought iron, as a marketing term used t distinguish it from the standard product, it is expected to "aid substantially" in reducing losses stemming from

Develop New Wrought Iron

PITTSBURGH, Feb. . M. Byers Co., a produ rought iron products, ounced today its metallu ave come up with a ne mproved version of sta rought iron.

Called 4-D wrought imply a marketing term o distinguish it from tandard product, it is ex o "aid substantially" in ng losses stemming from

A. M. Byers Co Develops New Wrought Iron

Dow-Jones Service

'ITTSBURGH, PA., Feb. 13 M. Byers Company, produc wrought iron products, nced its metallurgists ha e up with a new and ved version of stand ught iron.

alled 4-D wrought iron, sim marketing term used to dist sh it from the standard pr , it is expected to aid s ially in reducing los ming from material failu s d by corrosion, B. M. president, stated.

. S. Chalfant, vice preside s, said the new product on the market immediat added that the new prod

Civil Engineer C. E. Drummond (left), examines 4-D Wrought Iron sponge ball with J. A. Cain, A. M. Byers Company southeastern division manager. Laboratory test results have shown the new metal to be much

Developed By Byers

New Wrought Iron 25 Per Cent More Corrosion Resistan

250,000 Non-Rusting Fibers Per Square Inch In Product

By W. L. RUSSELL, Press Business Editor

Out of the laboratory and into production a Byers Co. has come a new type of wrought iro is credited with increasing corrosion resista much as 25 per cent.

The new 4-D is a result of 17 years of rese

In addition to superior resistance to corros new iron has greater uniformity and improved phys mechanical properties.

by substantially increasing the

4-D WROUGHT IRON

. Byers Co. Markets Kind of Wrought Iron

RGH (AP)—A. M. Byers wrought iron, developed after 17 the market today a years of research, has greater of wrought iron de- uniformity and better physical the most significant and mechanical properties. in the history of the

iption was given at a The key to manufacture of 4-D ence yesterday by B. wrought iron is removal of more oxygen from the base metal—

ykoskey, General Superintendent of Motive Baltimore & Ohio Railroad, gets a first hand om R. G. Angell (left), A. M. Byers Co. Railroad anager, on the increased corrosion resistance -D Wrought Iron. Byers recently announced a provement in wrought iron which makes the at least 25% more corrosion resistant than wrought iron. Railroads are among the world's sers of corrosion resistant wrought iron.

A. M. BYERS DEVELOP NEW WROUGHT IRO

PITTSBURGH, Feb. 13—(DJ A. M. Byers, Co., a producer o wrought iron products, announced its metallurgists have come up with a new and improved version of standard wrought iron.

Called 4-D wrought iron, simply a marketing term used to distinguish it from the standard product, it is expected to "aid substantially" in reducing losses stemming from material failures caused

Corrosion Resistance Raised in Wrought Iron

PITTSBURGH, Feb. 15 (AP) The A. M. Byers Company has announced development of an improved type of wrought iron highly resistant to corrosion.

Known as 4-D wroug the product is the re seventeen years of re the company said.

B. M. Byers, preside the new wrought iron by removin from the base refined iron—purer state g.

'New' Wrought Iron Developed

Production by A. M. Byer Company, Pittsburgh, Pa of a new "4-D wrought iron with 25 per cent increase

A. M. BYERS DEVELOPS NEW WROUGHT IRON

A. M. Byers Co., a producer of wrought iron products, announced its metallurgists have come up with a new and improved version of standard wrought iron. Called 4-D wrought iron, simply keting term

4-D Wrought Iron Cuts Corrosion

Out of the labo

Here is news. It's about one of the most significant metallurgical advances of modern times: the increased corrosion resistance of new 4-D Wrought Iron. This improved metal provides longer service life at lower cost per year. You can get further details from the Byers representative or by writing direct: A. M. Byers Company, Clark Building, Pittsburgh 22, Penna.

Byers Making New Wrought Iron

t significant development istory of wrought iron — new 4-D wrought as just been announced Byers Company.

s conference Tuesday m B. M. Byers, president m which is the world's oducer of wrought iron old newsmen:

condensates.

According to E. P. Best, Byers chief metallurgist, the improved 4-D wrought iron was achieved by substantially increasing the deoxidation of the base metal; increasing the phosphorous content in relation to the other material components; and using fiberous material.

ught Iron More Resistant

ught iron whose corrosion re- is increased 25% over standard iron is available. Marketed he name 4-D Wrought Iron, duct is the result of 17 years rch, laboratory and in-service

mproved wrought iron is made uniform di fiber throug

Also bec the metal i standard wr mechanical

4-D wrou ing product

Byers Develops New Wrought Iron

PITTSBURGH, Feb. 13. — A. Byers Co., a producer of wrou iron products, states its met urgists have come up with a and improved version of stand rought iron.

Called 4-D wrought iron, sim a marketing term used to dis guish it from the standard p uct, it is expected to "aid subs tially" in reducing losses stemm

Placed

A. S. Chalfan sales, stated th is simply a ma to distinguish th from standard w be placed on th ately and would the Byers Comp

ROUGHT IRON IMPROVEMENT IS REPORTED

Out of the laboratory and into production has come "new 4-D Wrought Iron" with 25% increased corrosion resistance, A. D. Sheere, A. M. Byers Co. Pacific Coast manager, announces.

Mr. Sheere, of San Franc recently returned from Pittsb where he was given a previe the new material. He says Wrought Iron is immediately able—at no increase in price will save millions of dolla corrosion losses annually i Pacific Coast territory.

According to Mr. Sheere, 4-D Wrought Iron was achiev increasing the purity of the increasing its phosphorous co and using a more siliceous silicate. Wrought iron is

New Wrought Iron Is 25 Per Cent More Corrosion Resistant

A new type of wrought iron, developed in the laboratories of A. N. Byers Co., Pittsburgh, is now in production. It is cred ited with increasing corrosion resistance as much as 25 per cent. The new metal, known as "4-D" is the result of 17 years

Byers Improves Wrought Iron

Special to the Herald Tribune

PITTSBURGH, Feb. 12.—A. M. Byers Co. announced today that it had developed a new kind of wrought iron, shown by tests to offer "greatly superior resistance" to corrosion.

Called "4-D," the improved wrought iron was achieved by substantially increasing the deoxidation of the base metal; increasing the phosphorous con-

HYDROGEN ABSORPTION, EMBRITTLEMENT and FRACTURE of STEEL

By Arnold E. Schuetz, Research Department, Bridgeport Brass Company, Bridgeport, Conn. and W. D. Robertson, Hammond Metallurgical Laboratory, Yale University, New Haven, Conn.

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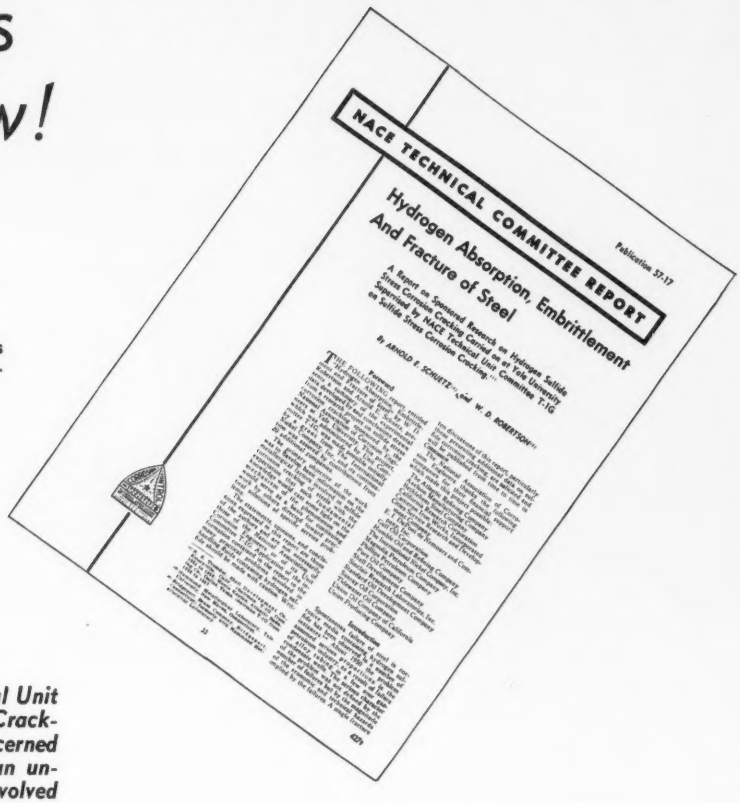

This 24-page illustrated report is replete with figures and tables on this basic research project's findings.

Basic Facts on Mechanism of Hydrogen Sulfide Stress Corrosion

The findings of a 4-year inquiry into the fundamental reactions involved in the so-called spontaneous fracture of steel as a result of hydrogen absorption in the presence of sulfides.

This project, supervised by NACE's Technical Unit Committee T-1G on Sulfide Stress Corrosion Cracking, was financed by industrial firms concerned with this problem in the expectation that an understanding of the fundamental reactions involved would lead to a solution.

Data in this report are expected to be useful not only in immediate steps to reduce the losses due to spontaneous failure but also as a foundation for subsequent inquiries into phenomena associated with hydrogen absorption and embrittlement of steel.

To: T. J. Hull, Executive Secretary
National Association of Corrosion Engineers
1061 M & M Bldg., Houston 2, Texas

Publication No. 57-17

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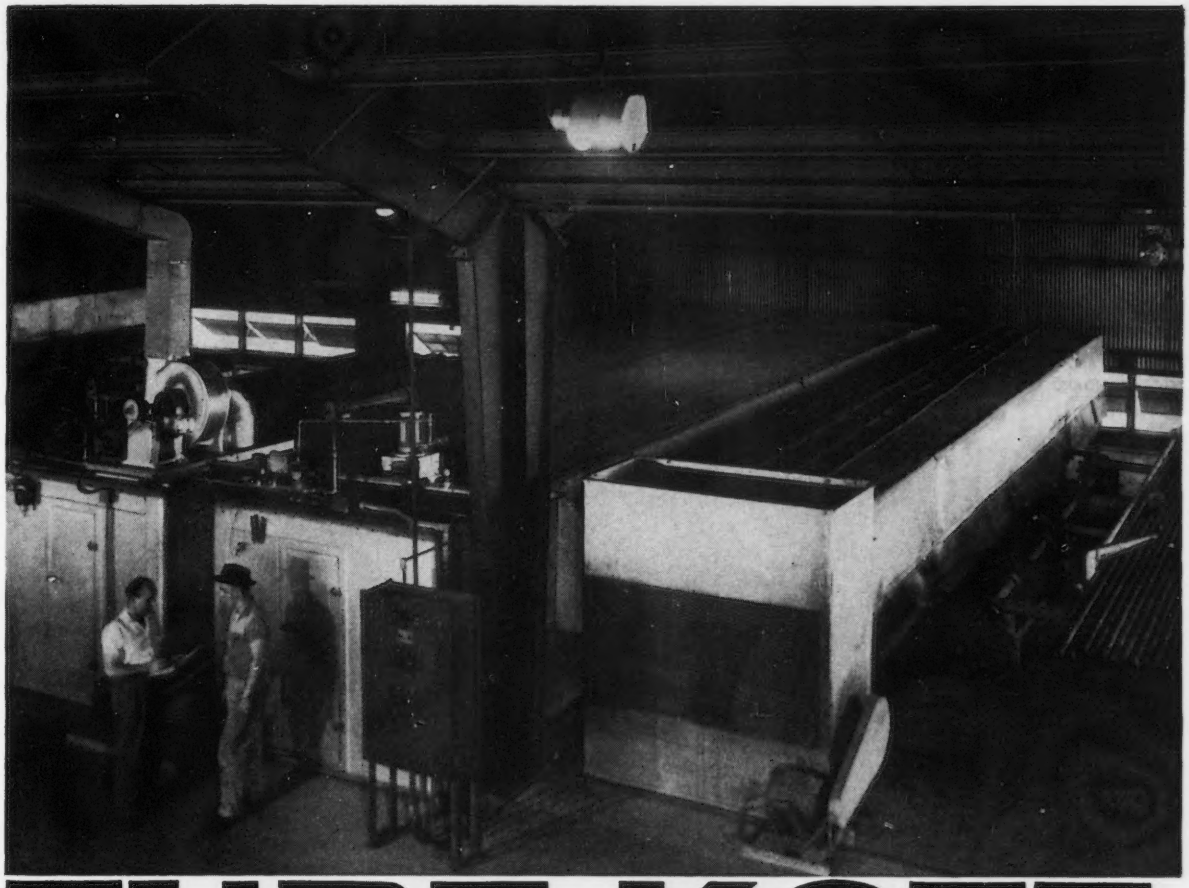
Another Contribution of NACE to the Understanding of Corrosion Processes



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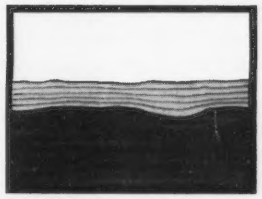
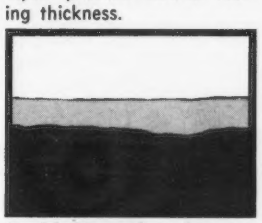


Coating flows into irregularities of pipe surface. Successive layers produce desired coating thickness.



Final baking polymerizes separate films into one uniform coating, permanently fused to the pipe surface.

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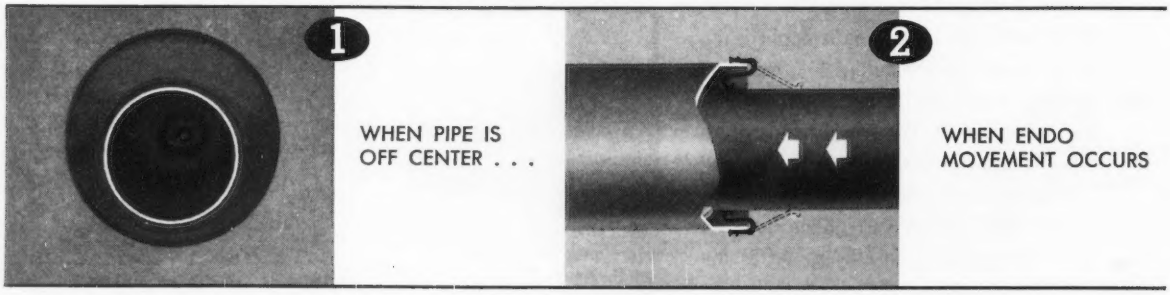

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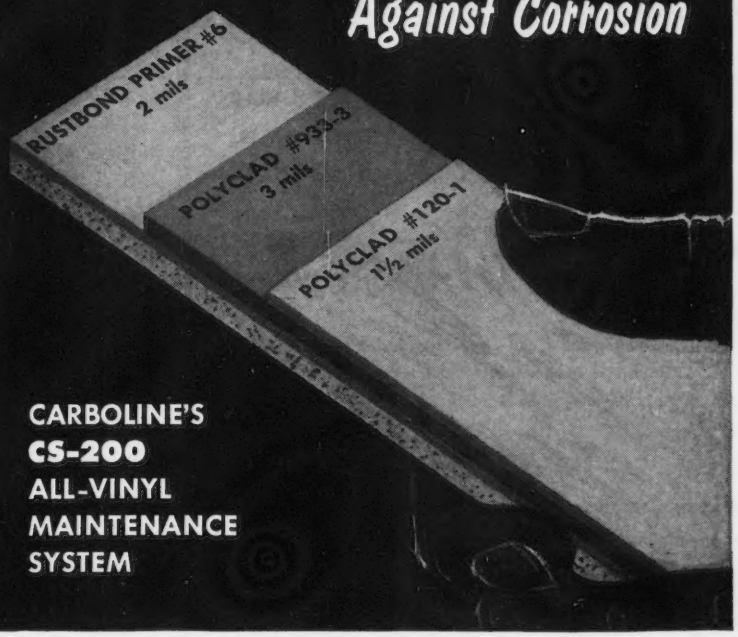
Against Corrosion



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(a) To promote the prevention of corrosion, thereby curtailing economic waste and conserving natural resources.

(b) To provide forums and media through which experiences with corrosion and its prevention may be reported, discussed and published for the common good.

(c) To encourage special study and research to determine the fundamental causes of corrosion, and to develop new or improved techniques for its prevention.

(d) To correlate study and research on corrosion problems among technical associations to reduce duplication and increase efficiency.

(e) To promote standardization of terminology, techniques, equipment and design in corrosion control.

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Corrosion

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Topic of the Month

Use of Magnesium Anodes to Protect Steel Mains

By HAROLD C. BOONE*

Introduction

A LARGE gas distribution company recently found it necessary to extend the length of a tunnel which housed one of its 30-inch cast iron mains. The tunnel had been built under a river near the turn of the century and was constructed of masonry. During the course of years following construction of the tunnel, the roof of the drift was damaged by an anchored vessel and severe water leakage into the tunnel resulted. In order to overcome the leakage, the drift was closed with concrete, which in turn cut off the accessibility of the main to inspection and maintenance.

Because the old main was inaccessible, it was concluded that during reconstruction a welded steel main should be installed inside the 30-inch cast iron pipe through the drift.

At the beginning of the reconstruction work, the cast iron main was taken out of service and an internal survey of the main's alignment was made. The survey disclosed a number of humps and bows in the 400-foot section which made it necessary to limit the size of the new steel main to 20-inch.

Application of Cathodic Protection

Various methods of cathodic protection were considered in the initial stages of planning the installation of the steel section of main under the river. Because of the problem of (1) obtaining the right of way and (2) maintaining electric service for the rectifier-groundbed type of system, it was decided that a cathodic protection system of galvanized anodes should be used. In addition, the galvanic anodes would be less likely to give any interference in this congested area of underground utilities.

Since the two shafts of the tunnel normally were filled with water, the problem of placing magnesium anodes along the 24-inch pipe in the 9-foot diameter shafts was relatively simple. In order to make the anodes in the shaft readily accessible for future replacement, threaded brass bolts were installed at the anode location in the wall of the shaft and disk-type anodes were held in place with a brass nut. The magnesium anodes were insulated from the brass bolts and the wall of the shaft. The individual anodes were connected to a collector wire which was brought to a point above the water line in the shaft in order that the total anode current could be read at any time.

The tunnel was to be drained every five years for a periodic inspection. On inspection, should the anodes need replacing, the old anode cores could easily be slipped from the brass bolts and replacements made. However, it was expected that the eleven-pound bare magnesium anode would last through several inspection periods and still give adequate cathodic protection to the pipe and steel brackets in the shafts.

Use of Magnesium Rods

To accomplish the same thing on the 20-inch steel pipe inside the 30-inch cast iron pipe in the drift was not as simple. The two principal difficulties were (1) to get the magnesium anodes along the pipe inside the casing pipe and (2) to obtain a desired 30 years of magnesium anode life.

A study of the problem indicated that the anodes must be pulled into the casing on the pipe, and that this could best be accomplished by attaching the anode on each of the insulated casing bands. The casing insulator bands were placed every ten feet to facilitate pulling the pipe over the humps and bows in the casing.

A search of magnesium anode manufacturers showed that anodes molded to fit the curvature of the pipe were not available; however, it was found that the 1.05-inch diameter steel core magnesium rod was available and could be fastened to the casing insulators between the runners.

As shown in Figure 1, 14 pieces of magnesium rod each seven inches long were attached to the casing insulator band with insulated steel cable. The anode leads were brought out from the anode in groups of seven and attached to the steel main. Each anode rod weighs approximately one-half pound, so seven pounds of magnesium were distributed along the main at ten-foot intervals. The anodes were insulated from the steel band of the casing insulators with a pad of rubber, and ends of the anodes were coated with pipe coating to reduce the anode surface area exposed. It was necessary to reduce the exposed anode surface areas in order to get the desired number of years of cathodic protection.

In addition to the corrosion protection supplied by the anode current, the resulting action between steel and magnesium will deplete the oxygen in the captive water around the pipe (in the sealed casing) and further reduce the rate of corrosion on the steel pipe.

It is believed that the magnesium anodes will provide adequate protection for over 30 years. Calculations of protective life were based upon the excellent pipe coating and the resistance of the tunnel water.

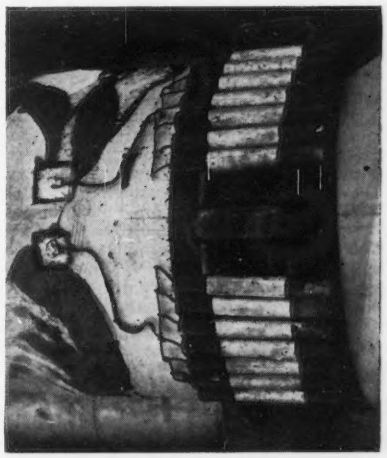

Figure 1—Magnesium rods attached to casing insulator band with insulated steel cable.

* The Peoples Gas Light and Coke Company, Chicago, Illinois.

The Activation and Inhibition Of Corrosion of Metals by Metallic Cations*

By W. ROGER BUCK, III and HENRY LEIDHEISER, JR.

Abstract

A broad survey was made of the corrosion of aluminum, cadmium, copper, gold, iron, magnesium, manganese, molybdenum, nickel, silver, tin, titanium, tungsten, zinc, and zirconium by fruit and mineral acids at the boiling point in the presence of low concentrations of foreign metallic ions. As a general rule, cations of the elements in groups II through V in the periodic table showed the highest tendency to decrease the rate of corrosion and the transition elements in group VIII showed the highest tendency to increase the rate of corrosion. The relative effectiveness of the ions was a function of the metal undergoing corrosion and the acid used. As far as could be determined, all the metallic ions which affected the corrosion rate did so by virtue of plating out on the metal surface. However, the adherence of the depositing metal did not appear to be related to the effect of the depositing metal on the corrosion rate. The activators and inhibitors altered the corrosion rate at concentrations as low as 10^{-7} to 10^{-5} M. These concentrations are equivalent to 0.1 to 10 atomic layers of the added metal if it is assumed that all the ions end up on the metal surface. In many cases when the added ion was a neighbor in the periodic table of the metal undergoing corrosion, an unusual rate of corrosion was obtained. As examples of this fact, copper was an effective inhibitor for the corrosion of nickel by hydrochloric acid and antimony was an effective activator for the corrosion of tin. 3.4.8

Introduction

DURING RESEARCH on the corrosion of metal single crystals, the remarkable effectiveness of Sn(II) ions in reducing the corrosion of single crystals of iron and steel by citric acid at the boiling point was noted.[1] Although the reduced corrosion of steel in fruit acids containing Sn(II) is well known,[2, 3, 4] little work appears in the literature on the effect of small amounts of other metallic ions on corrosion. In order to understand better the effect of Sn(II) as an inhibitor and to see how general such effects are, a broad survey was made of the effect of 35 different metallic cations at 10^{-7} to 10^{-3} M concentrations on the corrosion rate of 15 metals in several boiling media.

Buck Leidheiser

ROGER BUCK is a senior research chemist at the Virginia Institute for Scientific Research, Richmond, Virginia. He received a BS degree in chemistry from the University of Richmond in 1935 and a master's degree in physical chemistry from Duke University in 1940. Before coming to the Institute in 1952 he did college teaching. He is a member of the American Chemical Society, The Electrochemical Society and The National Association of Corrosion Engineers.

HENRY LEIDHEISER, JR. is Assistant Director of the Virginia Institute for Scientific Research, a laboratory devoted to fundamental research in the physical sciences. Dr. Leidheiser holds the PhD degree in physical chemistry from the University of Virginia. His research interests are broadly in the field of the surface properties of metals and specifically in the fields of electroplating and corrosion.

Experimental Details

Cylindrical specimens, exposing surface areas of 4-8 sq cm, were corroded in 100 ml of boiling solutions containing a maximum of 0.001 mole/liter of foreign metal salt. Corrosion rates were determined by weight loss in an all-glass assembly consisting of a 250-ml Erlenmeyer flask with a 19-inch long reflux condenser. The top of the condenser was covered with an inverted beaker to prevent extraneous matter from dropping into the reaction flask. Specimens of a given metal, all approximately of the same area, were degreased and heavily etched to remove the strain introduced by machining to shape in a lathe. A final light etch was given in the corroding solution under test, followed by thorough washing in distilled water and storage in a desiccator. Whenever possible, the metallic cation was added as the salt of the acid being used in the corrosion test in order to avoid the introduction of a foreign anion. However, at the concentrations employed, 10^{-3}M or less, a foreign anion, such as chloride in citric acid, did not have any measurable effect on the corrosion rate.

The duration of an experiment was determined by the activity of the metal. In the case of manganese in citric acid, experiments were terminated of necessity in 15 minutes. With the less active metals such as copper, experiments were run for 16-48 hours. The corrosion rates reported are average values over the period of the experiment. These values are of use only for comparative purposes and have no absolute significance, since the rates were not always linear with time. The data are reported in many instances as a function of the position of the added metallic ion in the periodic table.

Results

Aluminum in 0.2M Citric Acid

All experiments were carried out at concentrations of added ion of 10^{-3}M and are summarized in Table 1. The rate of corrosion of the blank was so low that inhibitory effects could not be clearly defined. Hg(II), Bi(III) and the group VIII transition elements were activators and increased the rate appreciably.

Aluminum in 2M HCl

The results obtained in the presence of 10^{-3}M added metal ion are plotted in Figure 1 and results for the transition metals as a function of concentration are plotted in Figure 2. All the group VIII elements, to different extents, were activators and the elements in groups III and IV (Tl and Pb) were slight inhibitors. Mercury and indium were outstanding in that they increased the rate of corrosion more than the most active group VIII element, ruthenium. The extremely deleterious effect of mercury on aluminum is well known.

Aluminum in 0.6M Na_2CO_3

The results of this study are summarized in Table 1. The blank rate was very high but it was still possible to detect activation by the platinum metals, gold, iron, and chromium. Beryllium and

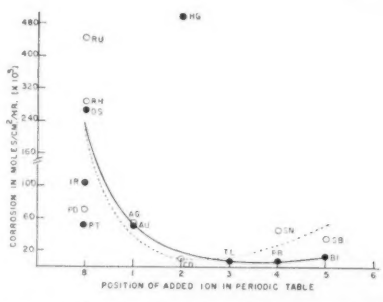

Figure 1—Corrosion rate of aluminum in boiling 2M HCl containing 10^{-3} M metal ions.

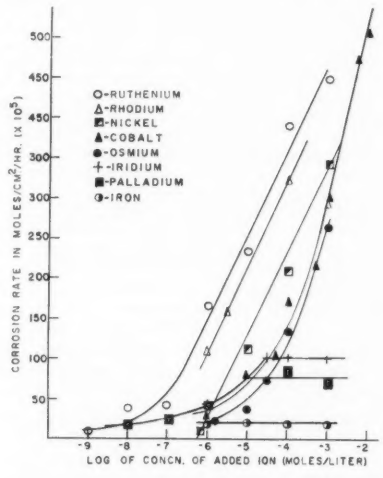

Figure 2—Corrosion rate of aluminum in boiling 2M HCl containing different concentrations of transition elements.

★ Submitted for publication February 24, 1958.

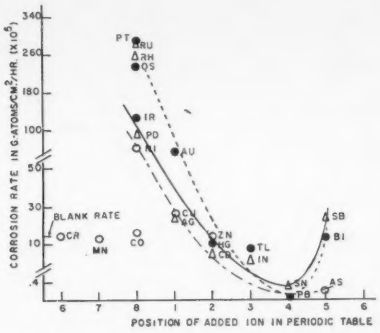

Figure 3—Corrosion rate of Armco iron in boiling 0.2M citric acid containing 10^{-3} M metal ions.

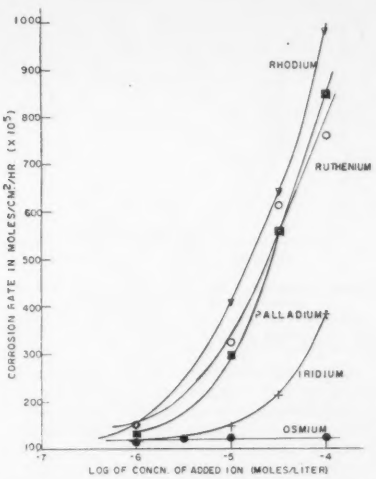

Figure 4—Corrosion rate of Armco iron in boiling 0.6M HCl containing different concentrations of transition elements.

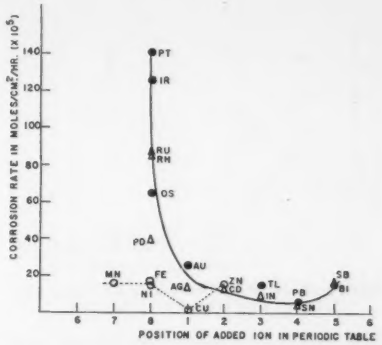

Figure 5—Corrosion rate of Nivac nickel in boiling 2M HCl containing 10^{-3} M metal ions.

tin, and to a lesser extent bismuth, were inhibitors and decreased the rate.

Cadmium in 0.2M Citric Acid

The effects of only four ions, namely, silver, indium, tin, and antimony, were studied when present in concentration of 10^{-3}M. The results are given in Table 1.

Copper in 2M HCl

The results obtained with 13 added ions are summarized in Table 1. It is not known whether a simple hydrogen evolution type reaction or another dissolution reaction occurred.

Gold in Constant Boiling HCl

Gold shavings did not corrode to any appreciable extent in constant boiling HCl containing 10^{-3}M concentrations of Ir(III), Rh(III), or Pt(IV).

Armco Iron in 0.2M Citric Acid

Corrosion rates obtained with Armco rod N in the presence of 10^{-3}M metallic ions are given in Figure 3. The striking correlation between the effects of the added ion and the position of the added ion in the periodic table is evident. Tin and lead from group IV and arsenic from group V were the best inhibitors and the transition elements in group VIII were the best activators. Ruthenium increased the rate about 20-fold, whereas tin decreased the rate to 3 percent of its blank rate.

In the case of those elements less active than iron, a deposit of the added metal soon became visible on the iron surface. However, in the case of the effective inhibitor, tin, the deposit was scarcely visible even at the end of the run. In the majority of cases the deposits were non-adherent. No correlation between deposit appearance and effect of the second metal on the corrosion rate was detected. Non-flaking deposits were obtained with tin, lead, cadmium, and nickel, to mention four, yet nickel was an activator and the other three metals were inhibitors.

Armco Iron in 0.6M HCl

A few measurements were made on the corrosion of iron in the presence of varying concentrations of transition elements.

TABLE 1—A Summary of Results Obtained and Not Included in Figures

	CORROSION RATE IN MOLES/CM ^{2}/HR (X 10^5)										
Added Ion in 10^{-3}M Concn.	**Aluminum in 0.2M Citric**	**Aluminum in 0.6M Na_2CO_3**	**Cadmium in 0.2M Citric**	**Copper in 2M HCl**	**Magnesium in 0.2M Citric**	**Manganese in 0.2M Citric**	**Molybdenum in 2M HCl**	**Silver in Constant Boiling HCl**	**Titanium in 2M HCl**	**Tungsten in 2M HCl**	**Zinc in 0.2M Citric**
Blank	0.15	140	0.04	0.54	1400	1800	nil	0.13	5.6	nil	5.4
Li (I)	0.15										7.6
Be (II)	0.11	9.0									5.4
Na (I)	0.11										8.5
Mg (II)	0.15	120									20
Al (III)											14.4
K (I)	0.15										7.6
Ca (II)		150									6.0
Sc (III)									6.1		
VO (II)									4.4		
Cr (II)	0.15	200				1900			5.0		
Mn (II)	0.15	120			very fast				5.0		
Fe (II)	0.19	230				2000	nil		5.0		
Co (II)	0.33	150		0.50			nil		7.1	nil	
Ni (II)	0.15	130		1.6			nil		10.4	nil	
Cu (II)	0.48	130			very fast				9.4		
Zn (II)	0.11	140									
As (III)	0.11					2300					
Rb (I)											4.5
Sr (II)											7.4
Ru (III)	0.44	230		1.4		1900	nil	0.9	nil	nil	95
Rh (III)	0.44	290		37			nil	1.4	nil	nil	80
Pd (III)	4.4	180		0.44			nil	0.37	nil	nil	86
Ag (I)	0.15	150	1.6	0.90		1900			5.8		45
Cd (II)	0.15	120			very fast	1900			5.8		12.5
In (III)	0.22	140	1.8			140			6.1		
Sn (II)	0.74	12	0.25	0.82		2100			6.7		
Sb (III)	0.26		2.4						nil		
Cs (I)	0.15										6.8
Ba (II)											5.8
La (III)	0.15				very fast						3.4
Os (III)	0.93			4.1		1700	nil	0.48	2.5	nil	
Ir (III)	0.33			15.1		1800	nil	1.0	nil	nil	
Pt (IV)	18.1	220		76			nil	0.9	nil	nil	
Au (I)	0.15	190		0.54					nil		
Hg (II)	152	slight gain		slight gain	very fast				6.5		
Tl (I)	slight gain	140				1900			7.5		
Pb (II)	slight gain	130		2.7	very fast	1600			6.3		
Bi (III)	507	80									

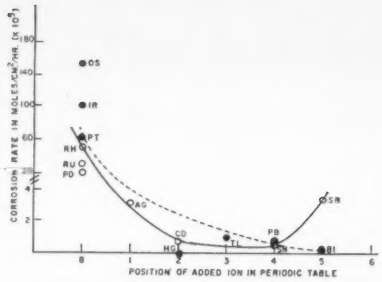

Figure 6—Corrosion rate of Nivac nickel in boiling 2M H_2SO_4 containing 10^{-3} M metal ions.

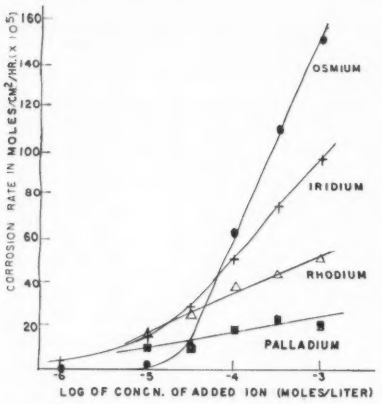

Figure 7—Corrosion rate of Nivac nickel in boiling 2M H_2SO_4 containing different concentrations of transition elements.

These results are summarized in Figure 4. The slopes of the curves of corrosion rate versus log of concentration of added ion were approximately the same for rhodium, ruthenium, palladium, and iridium. Osmium had no significant effect on the corrosion rate at concentrations as high as 10^{-4}M.

Magnesium

Magnesium specimens were very active in boiling citric acid. As shown in Table 1, none of the six added ions significantly changed the corrosion rate.

Manganese in 0.2M Citric Acid

Manganese corroded at a very fast rate which was not significantly affected by the presence of ions of arsenic, cadmium, chromium, iridium, iron, lead, osmium, silver, thallium, tin, or ruthenium, as shown in Table 1. Indium was unique in that it decreased the rate to about 8 percent of the blank rate.

Molybdenum in 2M HCl

No appreciable corrosion occurred in the presence of any added cation as shown in Table 1.

Nickel in 2M HCl

The results obtained in the presence of 10^{-3}M added cations are shown in Figure 5. Copper was outstanding as an inhibitor and lowered the rate to approximately 10 percent of the blank value. Only a very small amount of copper formed on the surface. The difference in color could be detected with certainty only by examining side by side a nickel specimen corroded in the presence of copper and one corroded in the absence of copper. All the platinum metals were effective as activators.

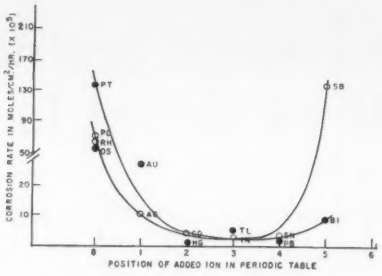

Figure 8—Corrosion rate of tin in boiling 2M HCl containing 10^{-3} M metallic ions

Nickel in 2M H_2SO_4

The results obtained in the presence of 10^{-3}M added cations are given in Figure 6. Inhibition was obtained, as in HCl, with ions in groups II and IV in the periodic table, plus bismuth from group V and copper from group I.

The effects of concentration of added platinum metal are summarized in Figure 7 for osmium, iridium, rhodium, and palladium. The results with nickel differed from those with iron and aluminum in that the slope of the corrosion rate versus log of concentration was not the same for each of the four platinum metals studied.

Silver in Constant Boiling HCl

As shown in Table 1, all six platinum metals were effective in increasing the rate of corrosion of silver. This ability to increase the corrosion decreased in the order: rhodium, iridium, ruthenium, platinum, osmium, and palladium.

Tin in 2M HCl

Two batches of tin obtained at different times were used. One lot corroded at a rate 4.4 times faster than the other. Analysis of the two batches indicated that the faster corroding material contained a higher antimony content. Since antimony proved to be a powerful activator for the corrosion it seems reasonable to attribute this difference in blank rate to the antimony content of the tin. Results with the added ions were consistent for the two samples of tin so only results with one sample are shown in Figure 8. A fine correlation of the corrosion rate with position of the added ion in the periodic table can be seen. Corrosion rates versus log of concentration of added ion are plotted in Figure 9 for iridium, ruthenium, antimony, and osmium.

Titanium in 2M HCl

The results obtained in the presence of 10^{-3}M added ions are summarized in Table 1. The platinum metals, antimony, and gold were effective inhibitors. A few of the metals, notably nickel and copper, increased the rate to approximately double its blank rate, but the majority of the metals had no major effect on the rate.

Corrosion runs were made as a function of concentration for both platinum and rhodium. In the presence of 10^{-5}M ions and above, titanium exhibited no corrosion. Between ion concentrations of 10^{-7} and 10^{-5}M, corrosion was decreased, and below concentrations of 10^{-7}M, the ions were without effect. Several samples which were exposed to rhodium concentrations greater than 10^{-5}M and showed no corrosion, were put in acid containing no metallic cations. No corrosion was exhibited after two hours in the boiling acid.

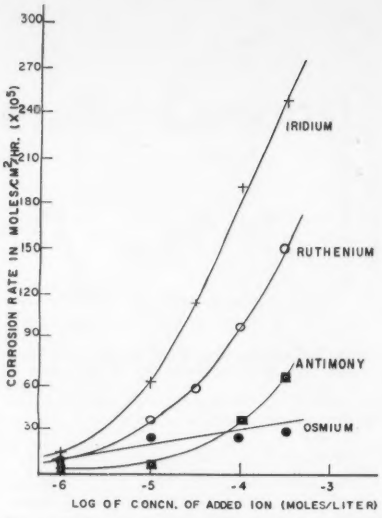

Figure 9—Corrosion rate of CP tin in boiling 2M HCl containing different concentrations of transition elements and antimony.

Tungsten in 2M HCl

As can be seen from Table 1 no appreciable corrosion occurred in the presence of any of the added ions.

Zinc in 0.2M Citric Acid

Measurements were made in the presence of 32 different cations at a concentration of 10^{-3}M on zinc of marine anode grade. These results are summarized in both Figure 10 and Table 1.

Zinc (99.999 percent) in 0.6M NaOH

The magnitude of the effects of the added ion was less in sodium hydroxide than in citric acid but there was no great difference in the relative effects in the two media as can be seen by a comparison of Figures 10 and 11.

Discussion

Although a number of investigators have made observations on several of the systems studied herein, no broad survey of the type carried out in this investigation apparently has been made.

Corrosion specialists know from experience that the platinum metals should be kept out of contact with less noble metals because of the great danger of galvanic corrosion, and it is generally appreciated by workers concerned with tinplate that tin ions are inhibitors for the corrosion of iron under anaerobic conditions. Such effects of metallic ions are generally attributed to a reduction or elevation of the hydrogen overvoltage of the surface or to a galvanic effect. This is natural in view of the fact that there is a parallelism in the relationship of the hydrogen overvoltage of the metals, the standard electrode potential, and the effect of the added metal on the corrosion with position in the periodic table.

This parallelism is far from perfect, however, as can be seen from a comparison of Figures 12 and 13 with Figures 1, 3, 5, 6, 8, and 10. It is the authors' feeling that the hydrogen overvoltage, the standard electrode potential, and the effects of the added metal on corrosion, all have their origin in the electronic properties of the metal. Corrosion rate is not a consequence of the other two, but all three effects can be traced back to a

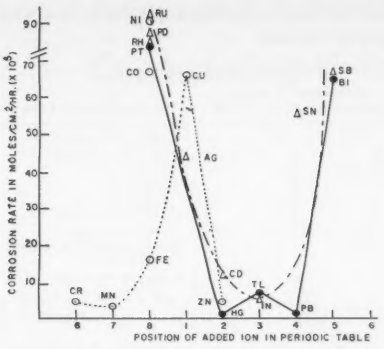

Figure 10—Corrosion rate of zinc in boiling 0.2M citric acid containing 10^{-3} M metal ions.

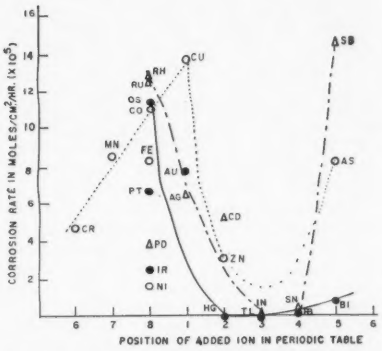

Figure 11—Corrosion rate of zinc in boiling 0.6M NaOH containing 10^{-3} M metal ions.

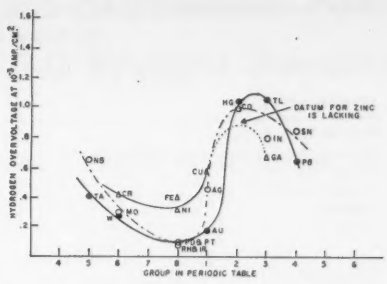

Figure 12—The relation between the hydrogen overvoltage of the elements and their position in the periodic table.

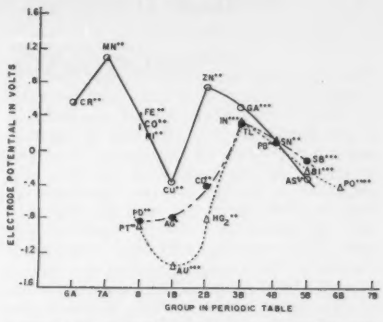

Figure 13—The relation between the standard electrode potential of the elements and their position in the periodic table.

TABLE 2—Order of Decreasing Effect in Inhibiting Corrosion

Iron	Aluminum	Nickel	Tin	Zinc
Lead	Lead	Mercury	Mercury	Mercury
Tin	Thallium	Tin	Lead	Lead
Indium	Cadmium	Indium	Tin	Indium
Cadmium	Indium	Cadmium	Indium	Thallium
Thallium	Tin	Lead	Cadmium	Cadmium
Mercury	Mercury	Thallium	Thallium	Tin

TABLE 3—Order of Decreasing Effect in Accelerating Corrosion

Aluminum	Iron	Nickel	Tin	Zinc
Ruthenium	Platinum	Platinum	Iridium	Ruthenium
Nickel	Ruthenium	Iridium	Ruthenium	Nickel
Cobalt	Rhodium	Ruthenium	Platinum	Palladium
Rhodium	Osmium	Rhodium	Palladium	Platinum
Osmium	Iridium	Osmium	Rhodium	Cobalt
Iridium	Palladium	Palladium	Osmium	Iron
Palladium	Nickel	Iron	Cobalt	
Platinum	Cobalt	Cobalt	Nickel	
Iron	Iron	Nickel	Iron	

common cause. The properties of the various systems are dependent upon how the electrons interact at the surface of contact between the two metals. This electronic interaction is moderately well understood in the cases of the thermoelectric force developed between two metals and the contact potential difference. Corrosion under the conditions studied in this investigation is a much more complicated phenomenon, however, since not only does it involve two metals and an aqueous medium, but it is a rate process with all the consequent difficulties of understanding the factors which govern electronic transition probabilities.

Before presenting a comprehensive interpretation of the experimental results, two additional types of studies must be carried out: (1) Studies of the effect of galvanic coupling of one metal to another under conditions where the ions of the second metal cannot come into contact with the corroding metal, and (2) Studies of the effects of anions on the corrosion of the 15 metals used in this investigation. Both of these studies have been started and encouraging results are being obtained.

As far as could be determined, all the metallic ions which affected the corrosion rate did so by virtue of plating out on the metal undergoing corrosion. Deposits of the added metal were visible only when the concentration exceeded 10^{-5} to 10^{-4}M, but in some cases the deposit of the added metal was scarcely visible on the surface even at higher concentrations. The deposits in the case of tin on iron and copper on nickel must have been extremely thin because they could be detected only on careful examination at the end of the experiment. The adherence of the depositing metal did not appear to be related to the effect of depositing metal on the corrosion rate. Corrosion activators in some cases formed spongy, non-adherent deposits and in other cases apparently continuous, adherent deposits. Inhibitors also were observed which showed both types of deposits.

It is obvious from a quick perusal of the figures that corrosion of many of the metals was increased by the platinum metals and that inhibition occurred in most cases at groups II through V in the periodic table. In general, there was a smooth change in the corrosion rate as the atomic number changed for the elements forming a series from group VIII to group V. In several cases the effect of mercury was anomalous with respect to a smooth change with atomic number. It exhibited in some instances a lower rate than would be expected on the basis of its position in the periodic table and in other instances a higher rate (aluminum in acid, in particular). This anomalous effect of mercury may be a result of its low melting point and the consequent ability to form a continuous layer over the surface. Experiments should be carried out at concentrations lower than 10^{-3}M to determine if its effect is anomalous under conditions where very thin deposits only could be formed.

Titanium was unusual in that the platinum metals reduced the corrosion rate in HCl to a very low value. Similar observations have been made previously by Schlain[5] and by Uhlig and Geary.[6] The platinum metals may be effective because the atoms assume substitutional positions in the surface oxide film and thus stabilize it, or because they furnish sites for hydrogen evolution and protect disruption of the oxide film, or because the potential between the platinum metals and titanium is sufficient to form anodically a protective oxide film. It is not possible at the present time to decide between these and other interpretations of the results.

Relative Effectiveness of Cations

There were striking differences in the relative effectiveness of the added cations. As an example, the relative effectiveness of lead, tin, indium, cadmium, thallium, and mercury in inhibiting the corrosion of iron, aluminum, nickel, tin, and zinc are given in Table 2. It will be noted that lead was the most effective inhibitor for iron and aluminum, an effective inhibitor for tin and zinc, and ineffective with nickel. Mercury was an effective inhibitor for the corrosion of nickel, tin, and zinc, ineffective with iron, and a corrosion accelerator for aluminum.

If the relative effectivenesses of the transition metals are treated in the same manner, the decreasing order shown in Table 3 is obtained. From these data the transition elements can be ranked in the following *average* order of decreasing effectiveness:

Ruthenium
Platinum
Iridium
Rhodium
Osmium
Palladium

Nickel
Cobalt
Iron

This ranking, however, is good only as a generalization, and may not be valid in specific instances. Nickel, ranked low in the list, was very effective in increasing the corrosion of aluminum. Osmium, which is in the center of the list, was effective in increasing the corrosion of iron in citric acid, yet had no effect on the corrosion of iron in hydrochloric acid. These summations only point more clearly to the conclusion that the effects of the added metallic ions are a function of the metal subjected to corrosion and the medium in which the corrosion occurs.

In many cases, as shown in Figures 2, 4, 7, and 9, the rate of corrosion over a limited concentration range was a linear function of the logarithm of the concentration. No great importance is attached to this fact at the present time and the method of plotting was chosen for convenience only.

If the surface area of the metal undergoing corrosion is assumed to be of the order of five times that of the geometric area, a concentration of approximately 10^{-4}M of the metallic ion contains a quantity of the added metal sufficient to form a monolayer on the surface. Extrapolation of the linear portion of the curves for the group VIII activators results in an intersection of the blank rate at concentrations in the range of 10^{-7} to 10^{-5}M. These concentrations are equivalent to 0.1 to 10 atomic layers of the added metal if it is assumed that all the ions end up on the surface. Only a few experiments were carried out with inhibitor ions as a function of concentration. Here, likewise, the lowest concentration at which the inhibitory effect of the added ion could be observed was in the range of 10^{-7} to 10^{-5}M; the inhibition of the corrosion of iron by tin and of titanium by the platinum metals disappeared in the vicinity of 10^{-6}M.

One of the more unusual observations made in this survey was the anomalous corrosion rate obtained in some cases when the added metal was a neighbor in the periodic table of the metal undergoing corrosion. As examples of this fact, copper was a good inhibitor for the corrosion of nickel in HCl; antimony was a powerful activator for the corrosion of tin in HCl; nickel was very effective as an activator for the corrosion of iron; and copper was a strong activator for the corrosion of zinc in citric acid and NaOH. It was not possible to determine if this unusual effect was characteristic of all the corroding metals, since in many cases the energy relationships are such that the neighbors in the periodic table could not be converted to the free atom to any appreciable extent by reaction of the ion with the corroding metal.

TABLE 4—The Correlation of the Corrosion Rate of Iron in Boiling 0.2M Citric Acid with the Nickel Impurity Content

IRON SAMPLE	Corrosion Rate in Moles/sq cm/hr (X 10^5)	Ni Content of Iron
Battelle High Purity	9.1	0.0004% (actual)
Johnson-Matthey Spectrographic Rods	11	0.0002% (actual)
Armco Iron "N"	13	Unknown
Armco Iron "P"	21	Unknown
Plastiron	29	0.008% (typical)
Puron	30	0.0015 (approx.) (also contained less than 0.0005% Ir)
Ferrovac-E	33	0.005% (typical)
Type-L steel	28-49	0.01 to 0.03% (actual)

Transition Elements

The tremendous influence of some of the transition elements on the rate of corrosion suggests that perhaps a significant fraction of corrosion by aqueous solvents may be a result of the presence of impurities in the metal which catalyze the transition of the metallic atom to the solvated ionic state. Since nickel is a great activator for the corrosion of iron and analyses for nickel were at hand for a number of irons in this laboratory, a comparison was made between the rate of corrosion and the nickel content. This comparison is given in Table 4. It would be dangerous to draw broad conclusions from these results, but it will be noted that the irons with the lowest nickel contents corroded at the lowest rates and the irons with the highest nickel contents corroded at the highest rates. It should be stressed that the concentrations of nickel may be a qualitative indication of the purity of the material and the corrosion rates may not be directly related to nickel, but to some other material or the total content of impurity.

In the case of the corrosion of aluminum by HCl, the corrosion rate was appreciably increased at concentrations of ruthenium and palladium as low as 10^{-8}M. These results indicate that very small amounts of some elements can drastically affect the corrosion rate.

The results on the activation of corrosion may be of use in deciding on the composition of stripping solutions for the rapid removal of metal from a substrate of different material. The results may also be of use in deciding which activators are best for the rapid solution of scrap metal for conversion to salts.

Acknowledgment

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Any discussions of this article not published above will appear in the December, 1958 issue

Aqueous Corrosion of Uranium Fuel-Element Cores Containing 0 to 20 Weight Percent Zirconium*

By DANIEL R. GRIESER and EUGENE M. SIMONS

Abstract

A description is given of the design and operation of a windowed autoclave system employed in the study of corrosion by pressurized hot water. The device has been used to obtain time-lapse motion pictures of the swelling and rupture of deliberately defected zirconium-clad uranium specimens. A method is described by which corrosion rates were calculated from pressure and temperature measurements. A typical set of pictures taken during a test is presented, and corrosion rates are reported for uranium-0, 5, 10, 15, and 20 weight percent zirconium alloys subjected to 600 F water. 8.4.5

Introduction

INCREASED INTEREST in the use of water as a primary heat-transfer medium in solid-fuel reactors has prompted many studies of aqueous corrosion of reactor materials. Because unalloyed uranium is particularly susceptible to corrosion by water, considerable work has been done in an effort to circumvent the problem of fuel-element corrosion by alloying and cladding the uranium with resistant materials.

Zirconium has appeared as one of the promising alloying and cladding elements, for it has favorable nuclear properties and is exceptionally resistant to corrosion by high-temperature water. It has been found in work at low temperatures that alloys containing even slight additions of zirconium to the uranium (<20 weight percent) exhibit better corrosion resistance than does pure uranium.[1,2] Nevertheless, the corrosion of these high-uranium alloys can be serious, especially at water temperatures at or above 600 F. Consequently a cladding is needed, not only to retain fission products, but also to provide additional protection against corrosion. The possibility exists, however, that a defect can develop in the cladding. The core is then in contact with the water, and the volume expansion resulting from oxidation of the uranium can enlarge the defect. In fact, if the mechanical strength of the bond between the cladding and core is weak, progressive oxidation may well result in complete destruction of the fuel element, even though the initial defect is but a small pinhole.

Factors which might affect this failure are the strength properties of the cladding material, the bond strength between the core and cladding, the operating temperature, the geometrical shape of the fuel element, the impurities in the water, and the corrosion rate of the core.

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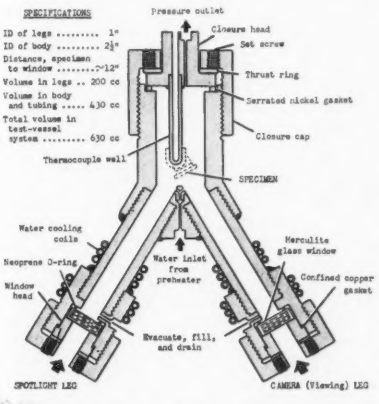


Figure 1—Cross section of windowed autoclave.

Grieser Simons

DANIEL R. GRIESER is a principal physicist in the Engineering Mechanics Division of Battelle Memorial Institute. He has worked on problems concerning the development of reactor components since joining the staff in 1953. He attended Antioch College for several years, completing the study for his BS in physics at The Ohio State University just prior to joining the Battelle staff. Mr. Grieser is a member of The Nuclear Engineering Division of the American Institute of Chemical Engineers.

EUGENE M. SIMONS is a consultant at Battelle Memorial Institute, Columbus, Ohio, in the division that is concerned with research in engineering mechanics. As such, he is particularly interested in reactor engineering and problems of lubrication, design, heat transfer and thermodynamics. Dr. Simons joined the Battelle staff in 1943. Previously he was an assistant professor of mechanical engineering at Virginia Polytechnic Institute. Other academic positions he held were at Marshall College and Carnegie Institute of Technology. Dr. Simons received a BS from Carnegie Institute of Technology, an MS from Virginia Polytechnic and a PhD from The Ohio State University—all in mechanical engineering.

A major portion of this investigation was the development of a windowed autoclave with which this rupturing phenomenon could be studied. This device was fitted with a time-lapse motion-picture camera to permit the observation of the physical changes in the specimen and the evolution of hydrogen, as bubbles, during the corrosion process. A recording pressure gage provided quantitative data on hydrogen-evolution rates. Information obtained in this fashion, together with geometrical considerations, was used to calculate corrosion rates.

Initial experiments were concentrated on finding the effects on the core-corrosion rate of (1) water temperature, (2) percentage of zirconium in the core alloy, and (3) the presence or absence of cladding.

Apparatus

In order to study the reaction of defected specimens in high-temperature water, the autoclave system was designed to withstand temperatures up to 700 F and pressures up to 3000 psi. The test vessel is the windowed autoclave pictured in Figure 1. Two Herculite glass windows are mounted at the ends of legs extending downward from the main body of the autoclave. Cooling the legs maintains the water inside them at a low enough temperature to avoid etching of the glass, and the useful life of the windows is thus extended indefinitely. Since the cooler, more dense water is in the lowest part of the autoclave, there is no tendency for convection currents to disrupt the optical path.

Water is raised to the test temperature in a separate preheat autoclave, shown in Figure 2. Therefore, no reacting of the defected specimen takes place until this elevated-temperature water is allowed suddenly to engulf the preheated test specimen. It is felt that this more closely simulates the effect of an actual defect occurring in a fuel element during reactor operation.

An arrangement of mirrors, a light source, and a digital timer, along with a time-lapse camera system, have been incorporated to record the visible change in the specimen during a test. The optical system, shown in Figure 3, is adjusted so that a picture is taken simultaneously of the specimen and the

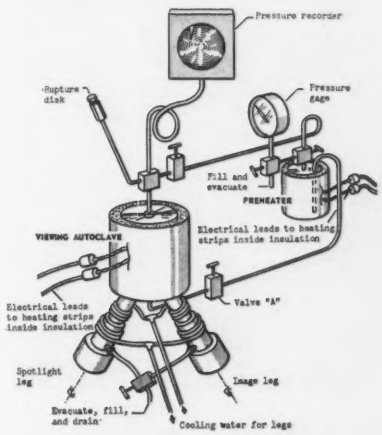


Figure 2—Windowed autoclave system.

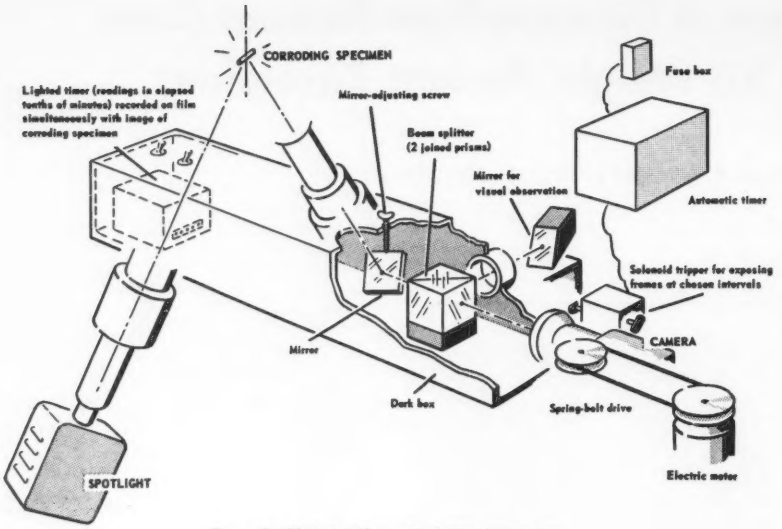


Figure 3—Photographing and observation system.

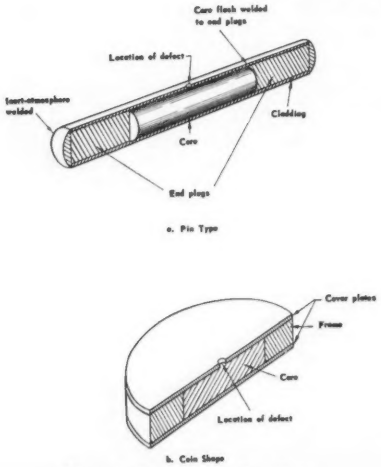


Figure 4—Specimen configurations.

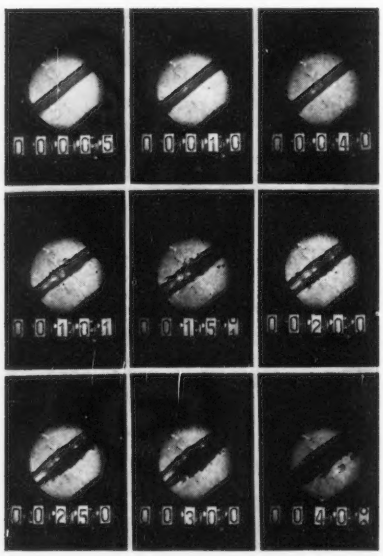


Figure 5—Representative reproductions from film of a test. Far right dial on digital timer indicates tenths of minute.

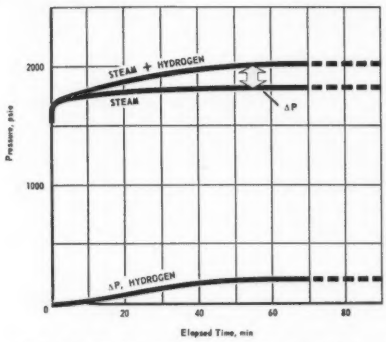


Figure 6—Typical plot of pressures versus time.

timer. Thus, each frame can be identified by the elapsed time from initial contact of the specimen with the elevated-temperature water. The remaining equipment in the system includes a pressure recorder for obtaining data on the total system pressure versus time, and valving and tubing to facilitate the initial charging with water and subsequent transfer of hot water from the preheat to the windowed autoclave.

Specimen Description

Two shapes of specimens were chosen for this series of tests, a pin shape and a flat disk. These were chosen both for their ease of fabrication and for their geometrical similarity to two common classes of fuel elements, rods and plates.

The pin-type specimens, depicted in Figure 4, were fabricated with uranium-0, 5, 10, 15, and 20 weight percent zirconium alloy cores. Although some specimens of each core alloy were fabricated with an attempt to produce a metallurgical bond, it was found after running several of them in the autoclave tests that unless the bond were exceptionally strong, separation would occur at the bond line adjacent to the reacted region. This made the evaluation of the instantaneous exposed core area, required for the corrosion-rate calculation, extremely difficult.

The coin-shaped specimen, illustrated in Figure 4, was chosen for investigating the effect of bonding on the corrosion rate, since this shape proved easier to handle analytically than the bonded pin shape. The specimens were fabricated by die pressing the loosely assembled pieces under vacuum at high temperature, and maintaining the pressure for several hours to effect bonding along all interfaces.

Data and Results

Data taken during a test include a film record, a pressure-time curve, and a temperature-time record. Figure 5 shows a sequence of frames selected from the film record of the reaction of a defected, clad, pin-type specimen containing a pure-uranium core which is being subjected to 600 F water. The 10-mil defect drilled through the zirconium cladding can be seen near the center of the specimen in the first few frames. The timer indicates that these nine frames span the time interval from 0.50 to 40.85 minutes. As can be estimated from the progress of the swelling, the reaction of the core at this temperature was quite rapid, and the cladding developed a split after less than 15 minutes. In this particular test, after only 40 minutes, the rupture had progressed to the point that oxide debris was falling onto the windows; by 50 minutes, the debris had completely obscured the view.

In the film records of a number of tests, however, it was possible to continue to see the specimen clearly until the entire core had been oxidized. When this happened, two independent methods of computing the corrosion rates were available. One was based on the total time required for the known volume of the core to be reacted, which could be obtained by studying the films and noting the instant at which the last bubble of hydrogen was evolved. The other made use of the rate of hydrogen evolution (as evidenced by the pressure and temperature records). In general, these two methods agreed within 20 percent, which is the estimated range of experimental error at best (based on the accuracy of the contributing data).

To determine hydrogen-evolution rates, it was necessary to subtract the steam pressure from the total system pressure and to correct for hydrogen solubility in the water. Steam pressures were determined from steam tables as vapor pressures corresponding to the measured water temperatures. Figure 6 shows a typical plot of total pressure, steam pressure, and hydrogen pressure. The hydrogen-evolution rate can be computed from this, with the aid of the perfect gas laws, since the gas volume and temperature are known. On the basis that the reacted uranium forms OU_2 (which has been verified by analysis of the debris), the hydrogen-evolution rate can be converted to moles of uranium oxidized per unit time. This is simply one-half the mole of hydrogen liberated per unit time.

Calculation of the corrosion rate per unit of exposed surface area requires a knowledge of the functional relationship between the instantaneous core area exposed to the water and the corroded volume. The analysis is presented in the Appendix, along with graphs of the geometrical relationships for the particular specimen shapes used in this study. As is generally done, the assumption is made that attack proceeds at a uniform rate in the direction perpendicular to the surface being corroded.

Table 1 gives average values of core-corrosion rates for various test and

TABLE 1—Average Corrosion Rates of Uranium and Uranium-Zirconium Alloys by Pressurized Hot Water

Nominal Zirconium Content (Balance Uranium), Weight Percent	Specimen Shape	Cladding Condition	Average Water Temperature, F	Average Corrosion Rate, mg/(sq cm) (hr)
0	Pin	Unclad	587	6,260
	Pin	Unbonded	582	4,910
	Pin	Unbonded	600	5,330[a]
	Pin	Unbonded	603	3,190
	Pin	Unbonded	605	3,800
	Pin	Unbonded	610	4,850
5	Pin	Unclad	587	3,150
	Pin	Unbonded	600	4,860
	Pin	Unbonded	612	6,300
	Coin	Bonded	595	2,120
	Coin	Bonded	600	4,440
10	Pin	Unclad	595	2,780
	Pin	Unclad	602	2,310
	Pin	Unbonded	570	2,330
	Pin	Unbonded	590	13,000
15	Pin	Unbonded	604	165[a]
20	Pin	Unbonded	610	194[a]

[a] Corrosion rates calculated from time required for complete oxidation of core, as ascertained from cessation of hydrogen bubbling on film record. All others computed from pressure records.

specimen conditions. To check the validity of the assumption of a constant corrosion rate, the values were calculated for several different intervals of time (Equation A-4 in the Appendix) in each case. Although some rates appeared to increase slowly while others seemed to decrease as the reaction progressed, the variation about the mean was in no case larger than 20 percent, and no correlation could be obtained with test conditions.

As will be noted in Table 1, the water temperature was rarely exactly 600 F. Factors determining the water temperature were too numerous to permit exact control. Thus, the uranium-0, 5, and 10 weight percent zirconium alloys are compared graphically in Figure 7 as a function of temperature. Since no other experimental data were available for comparison purposes in this temperature region, the lower temperature values of Mollison, English, and Nelson[3] were extrapolated to the 600 F range. This gave the straight line in Figure 7 which, though the validity of such extrapolation may be questioned, serves as an order-of-magnitude basis of comparison for the test points.

Discussion and Conclusions

The principal purpose of this investigation, as stated earlier, has been the development of a research tool. Toward this end, the relatively small number of tests run thus far have provided adequate evidence of both the flexibility and limitations of the windowed autoclave.

Data obtainable from the time-lapse photographs, although more qualitative than quantitative in nature, are of some value in his particular type of test because the swelling and rupture of the cladding resulting from the core reaction is clearly visible and serves to confirm the rapidity with which low-zirconium alloys of uranium are oxidized in high temperature water. In addition, by projecting the time-lapse film record of a test at the normal speed of 16 frames per second, it is possible to observe the manner in which a particular cladding configuration fails.

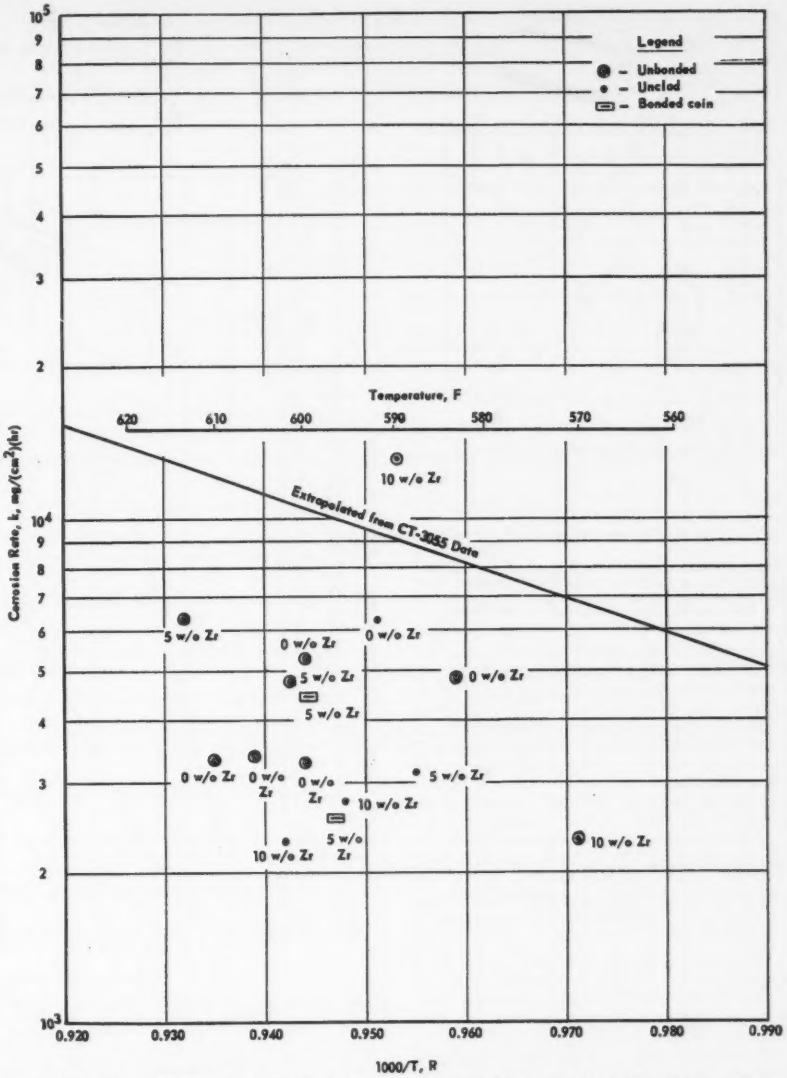


Figure 7—Average corrosion rates of uranium and uranium-zirconium alloys versus the reciprocal of temperature.

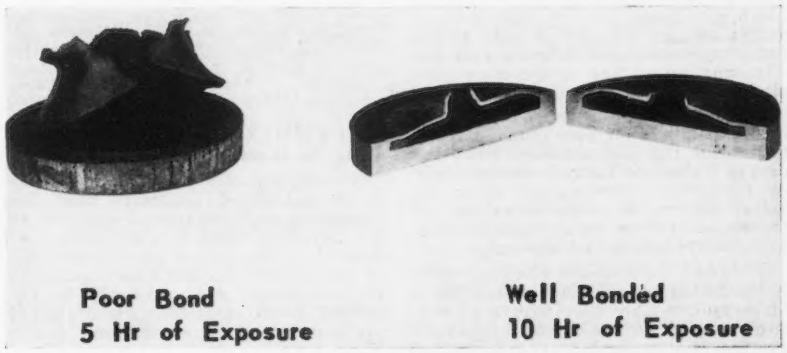


Figure 8—Rupture of bonded coin specimens of uranium-5 weight percent zirconium tested in 595-600 F water.

Since the swelling produced in the cladding is a direct result of the uranium in the core being converted to the less dense UO_2, it was felt that a more quantitative evaluation of the influence of various factors on specimen rupture could be made by means of the core-corrosion rate. For this reason, the method of determining the core-corrosion rate from the partial pressure of hydrogen was developed.

Although the results obtained from these tests have an accuracy no better than 20 percent (based on the accuracy

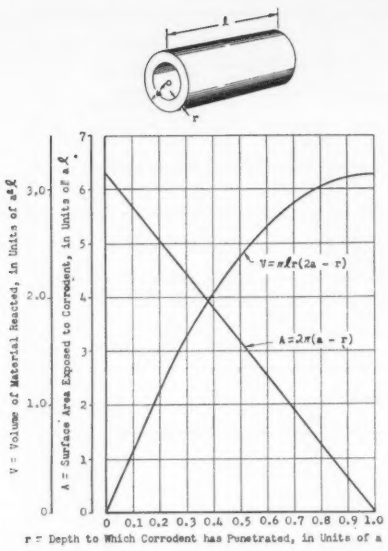

V = Volume of Material Reacted, in Units of a²ℓ
A = Surface Area Exposed to Corrodent, in Units of aℓ
V = πℓr(2a − r)
A = 2π(a − r)
r = Depth to Which Corrodent has Penetrated, in Units of a

Figure 9—Volume of material reacted and exposed surface area as functions of depth of corrosion. Case 1: Unbonded or unclad pin with protected ends; entire lateral surface exposed to corrodent.

with which the pressures, etc., can be measured), some conclusions may be drawn from the data based on order-of-magnitude comparisons. By referring again to the graphical representation of data (Figure 7), one observes that clad specimens react at nearly the same rate as unclad ones and zirconium additions up to 10 weight percent provide only slight protection to the uranium core. On the other hand, the corrosion rates of the 15 and 20 weight percent zirconium alloys were found to be an order of magnitude smaller than those of the pure uranium or the uranium-10 weight percent alloy.

The large dispersion of the experimental points in the unalloyed uranium and uranium-10 weight percent zirconium specimens overshadows any noticeable temperature effect; however, the data for the 5 weight percent zirconium alloy show a definite increase in corrosion rate at higher temperatures. This strong temperature dependence has been substantiated by other investigators and explains the sizable errors that may arise from difficulties in determining specimen temperature precisely.

The discrepancy between the experimental points of the pure uranium specimens and the line obtained from the data of Reference 3 may be due not only to the larger experimental error involved but to the doubtful validity of extrapolating from data at considerably lower temperatures into this range.

Although the corrosion rate apparently is unaffected by cladding or bonding a high-uranium-alloy core with a protective covering of zirconium, the rate of rupture is decreased as the degree of the bonding is increased. This is to be expected, since the core surface exposed through a defect in a bonded element will be considerably less than in one with no bond. An example of this may be seen in Figure 8. It will be noted that the rupture is less severe in the specimen with the stronger bond, and in fact, after twice the exposure, a section of the well-bonded specimen core was still unreacted.

$$V = 4\int_0^r\int_0^{\pi/2}\int_0^{\cos^{-1}\left(r\frac{\sin\theta}{2a}\right)} r^2 \sin\theta\, dr\, d\theta\, d\phi, \text{ for: } r \leq 2a.$$

$$V = 4\int_{2a}^r\int_0^{\sin^{-1}\left(\frac{2a}{r}\right)}\int_0^{\cos^{-1}\left(r\frac{\sin\theta}{2a}\right)} r^2 \sin\theta\, dr\, d\theta\, d\phi + 4\int_0^{2a}\int_0^{\pi/2}\int_0^{\cos^{-1}\left(r\frac{\sin\theta}{2a}\right)} \sin\theta\, dr\, d\theta\, d\phi, \text{ for } r > 2a.$$

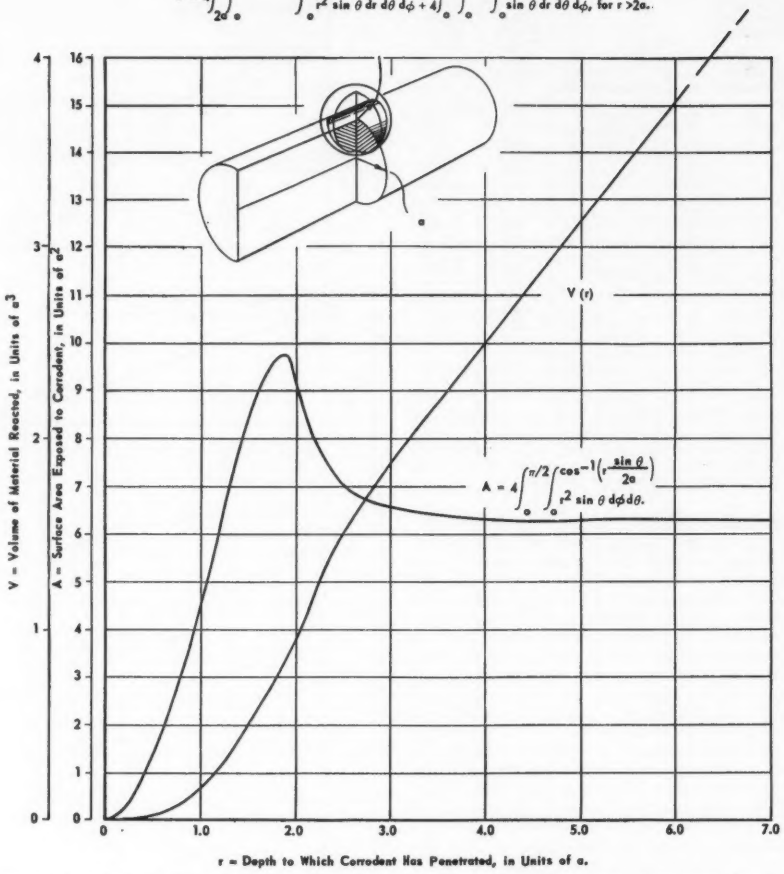

V = Volume of Material Reacted, in Units of a³
A = Surface Area Exposed to Corrodent, in Units of a²
V (r)
A = 4∫∫ r² sin θ dφ dθ
r = Depth to Which Corrodent Has Penetrated, in Units of a.

Figure 10—Volume of material reacted and exposed surface area as functions of depth of corrosion. Case 2: Bonded pin, contact of corrodent at localized area on lateral surface.

References

1. David W. Lillie, (Editor), Uranium Alloys Newsletter No. 6, WASH-153 (February 5, 1954), p. 12.
2. J. E. Draley, J. W. McWhirter, et al. The Corrosion of Low-Zirconium-Uranium Alloys in Boiling Water. ANL-5030 (April 14, 1953).
3. W. A. Mollison, G. C. English, F. Nelson, Corrosion of Tuballoy in Distilled Water, CT-3055 (June 23, 1945).

APPENDIX—Geometrical Considerations in Corrosion-Rate Calculations

A corrosion rate is one of the commonly calculated quantities used for comparing the resistance of materials to the corroding action of a particular medium. It is the rate of reaction per unit of macroscopic surface area exposed to the corrodent, and ordinarily is expressed as the mass of material reacted per unit area per unit of time. That is,

$$k = \frac{1}{A}\frac{dM}{dt}, \qquad (A\text{-}1)$$

where:

k = corrosion rate,
A = exposed area,
$\frac{dM}{dt}$ = time rate of mass reaction.

Using the relation:

$$V = M\rho, \qquad (A\text{-}2)$$

where:

ρ = mass density of parent material, and
V = volume of material reacted,

Equation (A-1) may be expressed as:

$$k = \frac{\rho}{A}\frac{dV}{dt}. \qquad (A\text{-}3)$$

If the area exposed is a function of the volume corroded: A = f(V) and the reaction rate, k, is a constant with respect to time, the equation may be arranged and integrated:

$$k = \frac{\rho}{(t_2 - t_1)}\int_{V_1}^{V_2}\frac{dV}{f(V)}. = \frac{\rho}{(t_2 - t_1)}R, \qquad (A\text{-}4)$$

where $(t_2 - t_1)$ is the time interval during which the corroded volume increases from V_1 to V_2,

and R represents the $\frac{\text{volume}}{\text{area}}$ integral.

If $t_1 = 0$ when $V_1 = 0$, Equation (A-4) becomes:

$$k = \frac{\rho}{t_2}R_0, \text{ where } R_0 = \int_0^{V_2}\frac{dV}{f(V)}. \qquad (A\text{-}5)$$

In order to apply this formula to a particular corrosion-rate calculation, the

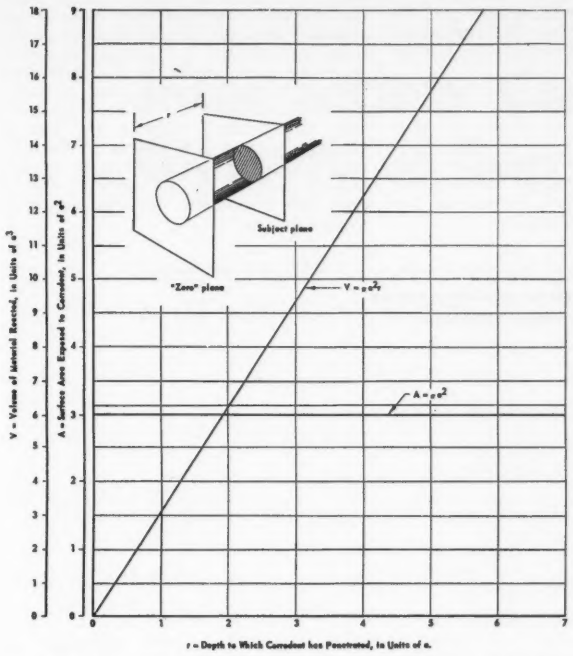

Subject plane
"Zero" plane
V = σ²r
A = σ²
V = Volume of Material Reacted, in Units of a³
A = Surface Area Exposed to Corrodent, in Units of a²
r = Depth to Which Corrodent has Penetrated, in Units of a.

Figure 11—Volume of material reacted and exposed surface area as functions of depth corrosion. Case 3: Pin with bonded lateral surface; corrodent contacts unbonded ends.

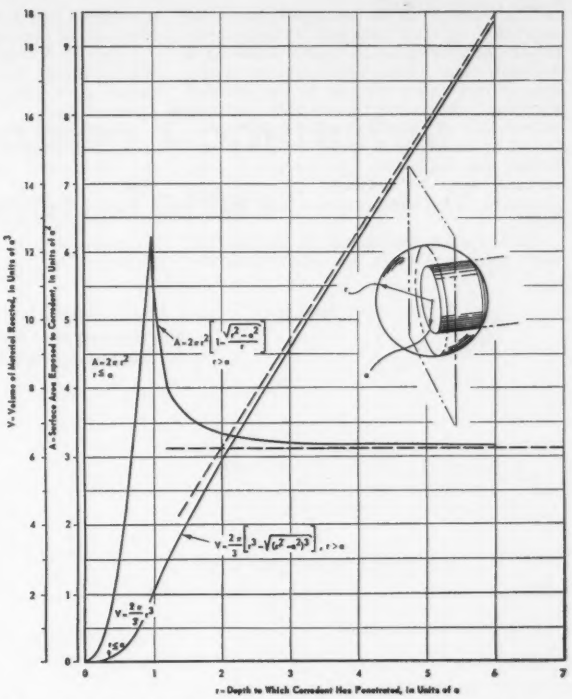

A=2πr²
r≤a
A=2πr²[1−√(r²−a²)/r]
r>a
V=(2π/3)r³
r≤a
V=(2π/3)[r³−√(r²−a²)³], r>a
V = Volume of Material Reacted, in Units of a³
A = Surface Area Exposed to Corrodent, in Units of a²
r = Depth to Which Corrodent Has Penetrated, in Units of a

Figure 12—Volume of material reacted and exposed surface area as functions of corrosion. Case 4: Bonded pin, corrodent initially contacts localized area at one end.

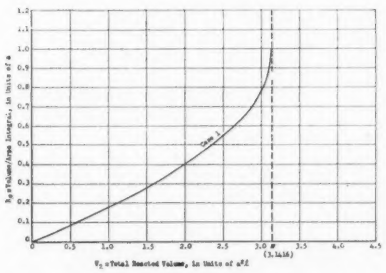


Figure 13—Volume/area integral as a function of reacted volume for an unbonded or unclad fuel pin with protected ends and entire lateral surface exposed to corrodent (Case 1).

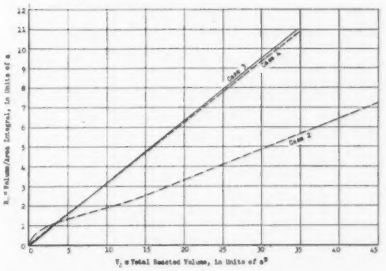


Figure 14—Volume/area integral as a function of reacted volume for fuel pins. Case 2 is for bonded side, bonded end, hole in side; Case 3 is for bonded side, unbonded end, hole in end; Case 4 is for bonded side, bonded end, hole in end.

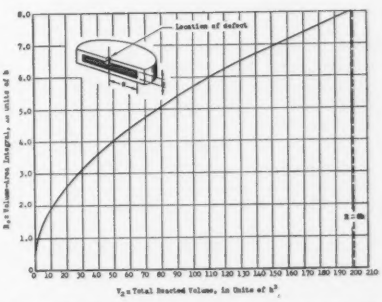
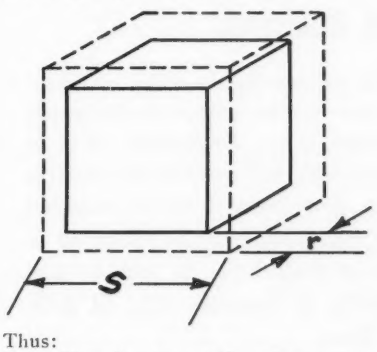


Figure 15—Volume/area integral as a function of reacted volume for completely bonded coin-shaped specimen with R = 8h. Pinhole is in center of one face.

specific geometry involved must be known, i.e., A = f(V). An example might be a cube with side length s, completely submerged in a corrosive fluid. Let r be a depth of corrosion.



Thus:

(a) $V = s^3 - (s-2r)^3$, volume corroded

(b) $A = 6(s-2r)^2$, instantaneous area exposed to fluid.

Solving (a) for r in terms of V:

$$r = \frac{s - (s^3 - V)^{1/3}}{2}$$

and substituting this value for r in (b) gives:

$$A = f(V) = 6(s^3 - V)^{2/3}.$$

Then, in the case of a cube, Equation (A-5) becomes:

$$k = \frac{\rho}{t_2} \int_0^{V_2} \frac{(s^3 - V)^{-2/3}}{6}\, dV.$$

Integrating yields:

$$k = \frac{\rho}{t_2} \left[\frac{(s^3 - V)^{1/3}}{(-2)} \right]_0^{V_2}.$$

And finally:

$$k = \frac{\rho}{2t_2} \left[s - (s^3 - V_2)^{1/3} \right],$$

where:

t_2 = length of time reaction has been going on

V_2 = volume reacted after time t_2.

The corrosion rate of a cube may now be calculated if one knows the density (ρ) of the material and the volume (V_2) that is reacted in elapsed time (t_2). This reacted volume might in turn be calculated from: (1) a weight change, (2) a change in dimensions, (3) the quantity of reaction products formed, or (4) the amount of a side product formed in the reaction.

In a similar manner, it is possible to calculate a corrosion rate for any case in which the geometry is known and the exposed area can be expressed as a particular function of the reacted volume. For illustrative purposes, this relationship is presented for four geometries which might be encountered in reactor

fuel elements. It is assumed that the corrosion of any exposed surface proceeds perpendicular to that surface at a uniform rate. Thus, when access to the core is through a pinhole in the bonded cladding, the corrosion would proceed spherically from that point. An additional assumption is made that the corroding medium has free access to the surface, with no masking by corrosion products. The sample cases are as follows:

Case 1—An unbonded or unclad pin with protected ends, in which case the corrodent has access initially to the entire lateral surface but not the ends.

Case 2—A completely bonded pin, in which initial contact of the corrodent occurs at a localized point on the lateral surface.

Case 3—A pin with a bonded lateral surface and an unbonded end, in which the corrodent has free access to this end.

Case 4—A completely bonded cylinder, in which the corrodent contacts the core initially at a point located at the center of one of the ends.

These four cases are presented graphically in Figures 9 through 12, in which the instantaneous corroded volume and exposed area are plotted against a common parameter, r, the instantaneous depth of penetration of the corrodent. The mathematical steps for obtaining the final relationships between corrosion rate and reacted volume are not included; instead, the results of the integration for the four pin shapes are presented graphically in Figure 13 and 14, and, for a bonded flat-disk shape, in Figure 15.

Any discussions of this article not published above will appear in the December, 1958 issue

DISCUSSIONS ON TECHNICAL ARTICLES ARE SOLICITED

Discussions on technical articles published in Corrosion will be accepted for review without invitation. Discussions must be constructive, accompanied by full substantiation of fact in the form of tables, graphs or other representative data and be submitted in three typewritten copies.

Authors of discussions are asked to supply one copy of figures suitable for reproduction and will be sent on request a copy of the NACE Outline for the Preparation and Presentation of Papers.

Discussions will be reviewed by the editor of Corrosion and will be sent to the author of the paper discussed for his replies, if any. Publication will be in the Technical Section with full credit to the authors together with replies. Discussions to papers presented at meetings of the association may be submitted in writing at the time of presentation or later by mail to the editorial offices of Corrosion, 1061 M & M Bldg., Houston 2, Texas.

Publication 58-9

Part 2

Inter Society Corrosion Committee Glossary of Corrosion Terms*

Submitted by the Subcommittee on Standard Definitions and Terminology*
At the 1958 Meeting of ISCC in San Francisco, California

Abstract

Definitions are given for some 50 commonly used corrosion terms. For certain terms, supplementary wording is included to make the definition more easily understood. 1.7.3

1. **ACTIVE**
   A state wherein passivity is not evident.

2. **AERATION CELL**
   See DIFFERENTIAL AERATION CELL.

3. **ANAEROBIC**
   Free of uncombined oxygen.

4. **ANION**
   A negatively charged ion or radical which migrates toward the anode under the influence of a potential gradient.

5. **ANODE**
   An electrode or portion of an electrode at which a net oxidation reaction occurs.

6.** **ANODE CORROSION EFFICIENCY**
   The ratio of the actual corrosion of an anode to the theoretical corrosion calculated from the quantity of electricity which has passed.

7. **ANODIC POLARIZATION**
   Polarization of anodes.

8.** **ANOLYTE**
   The electrolyte of an electrolytic cell adjacent to the anode.

9. **ANTI-FOULING**
   Pertaining to the prevention of marine organism attachment and growth on a submerged metal surface [through the effects of chemical action].***

10. **AUSTENITIC**
    The face-centered cubic crystal structure of ferrous metals.

11. **CATHODE**
    An electrode or portion of an electrode at which a net reduction reaction occurs.

12. **CATHODIC CORROSION**
    An increase in corrosion of a metal by making it cathodic.

13. **CATHODIC POLARIZATION**
    Polarization of cathodes.

14.** **CATHOLYTE**
    The electrolyte of an electrolytic cell adjacent to the cathode.

15. **CATION**
    A positively charged ion or radical which migrates toward the cathode under the influence of a potential gradient.

16. **CONCENTRATION CELL**
    An electrolyte cell, the emf of which is due to differences in composition of the electrolyte at anode and cathode areas.

17. **CORROSION**
    The deterioration of a substance [usually a metal]*** because of a reaction with its environment.

18. **CORROSION RATE**
    The rate at which corrosion proceeds.

19. **COUPLE**
    See GALVANIC CELL.

20.** **CRITICAL HUMIDITY**
    The relative humidity above which the atmospheric corrosion rate of a given metal increases sharply.

21. **CURRENT DENSITY**
    The current per unit area.

22. **DEACTIVATION**
    The process of removing active constituents from a corroding liquid [as removal of oxygen from water].***

23. **DEMINERALIZATION**
    The process of removing dissolved minerals [usually by chemical means].***

24. **DEZINCIFICATION**
    Parting of zinc from an alloy [PARTING is the preferred term]. [Other terms in this category, such as denickelification, dealuminification, demolybdenization, etc., should be replaced by the term PARTING].***

25. **DIFFERENTIAL AERATION CELL**
    An oxygen concentration cell.

26. **ELECTROCHEMICAL EQUIVALENT**
    The weight of an element or group of elements oxidized or reduced at 100 percent efficiency by a unit quantity of electricity.

27.** **ELECTROLYSIS**
    Chemical change in an electrolyte resulting from an impressed current.

28. **ELECTROLYTE**
    An ionic conductor.

29. **ELECTROMOTIVE FORCE SERIES**
    A list of elements arranged according to their standard electrode potentials.

30. **EQUILIBRIUM POTENTIAL**
    The electrode potential at equilibrium.

31. **EXFOLIATION**
    A thick layer-like growth of corrosion product.

32. **FERRITIC**
    The body-centered cubic crystal structure of ferrous metals.

33. **FOULING**
    The accumulation and growth of marine organisms on a submerged metal surface.

34. **GRAPHITIC CORROSION**
    Corrosion of gray cast iron in which the metallic constituents

★ This is the second in a series of corrosion term lists compiled by the ISCC. List No. 1 appeared in *Corrosion*, **14**, 71-72t (1958) Feb.

* A. de S. Brasunas, chairman. Members are J. L. English, H. C. Gatos, J. J. Harwood, R. A. Powers, Milton Stern, L. P. Sudrabin and Norman Hackerman (ex officio).

** Definition taken verbatim from Corrosion Handbook (H. H. Uhlig, editor), John Wiley and Sons, New York, 1948.

*** Portions shown within brackets [ ] are not required for the definition and may be deleted; they have been added to make the definition more easily understood.

are converted to corrosion products leaving the graphite intact.

35. **GRAPHITIZATION**
(1) Decomposition of a metal carbide to [matrix]*** metal and graphite.
(2) See GRAPHITIC CORROSION.

36. **HYDROGEN EMBRITTLEMENT**
Embrittlement caused by hydrogen.

37. **INHIBITOR**
A substance which retards corrosion when added to an environment in small concentrations.

38. **ION**
An electrically charged atom or radical.

39.** **OPEN CIRCUIT POTENTIAL**
The measured potential of a cell from which no current flows in the external circuit.

40.** **OXIDATION**
Loss of electrons by a constituent of a chemical reaction.

41. **OXYGEN CONCENTRATION CELL**
A galvanic cell resulting primarily from differences in oxygen concentration.

42. **PASSIVATOR**
An inhibitor which changes the potential of a metal appreciably to a more cathodic or noble value.

43. **PASSIVE-ACTIVE CELL**
A cell composed of passive and active areas.

44.** **REDUCTION**
Gain of electrons by a constituent of a chemical reaction.

45. **REVERSIBLE POTENTIAL**
See EQUILIBRIUM POTENTIAL.

46. **RUST**
Corrosion product consisting primarily of hydrated iron oxide. [A term properly applied only to iron and ferrous alloys.]***

47. **SPALLING**
Spontaneous separation of a surface layer from a metal.

48. **STRESS-ACCELERATED CORROSION**
Corrosion which is accelerated by stress.

49. **THERMOGALVANIC CORROSION**
Corrosion resulting from a galvanic cell caused primarily by a thermal gradient.

50. **WELD DECAY**
Localized corrosion at or adjacent to a weld.

** Definition taken verbatim from Corrosion Handbook (H. H. Uhlig, editor), John Wiley and Sons, New York, 1948.

*** Portions shown within brackets [ ] are not required for the definition and may be deleted; they have been added to make the definition more easily understood.

Publication 58-10

NACE TECHNICAL COMMITTEE REPORT

Report on Thermoplastic Coal Tar Base Linings

A Report of NACE Unit Committee T-6A on Organic Coatings And Linings for Resistance to Chemical Corrosion, Prepared by Task Group T-6A-16 on Coal Tar Coatings*

Abstract

The relative resistances to various chemical environments are given for thermoplastic coal tar base linings. Media to which these linings are exposed include 11 acids, 5 alkalies, 2 oxidizing agents, 3 fats and oils, 5 gases, 7 solvents, 12 salts, as well as to sodium hypochlorite and to tap, distilled and sea water. Physical and chemical properties are listed for both hot and cold applied coatings.

The application of coal tar base linings is considered in detail with special attention paid to such matters as coverage, surface preparation, priming, and application methods. 5.4.3

Definitions

THIS REPORT deals with thermoplastic coal tar base linings and does not include any information on chemically modified, thermosetting coal tar compositions.

Thermoplastic coal tar base linings are a class of materials in which protection of the substrate from corrosion is provided largely by coal tar pitch. This pitch is produced from coal tar, recovered in the manufacture of coke, by distillation to remove enough of the lower boiling constituents to obtain a residue of the desired consistency. Products for use as linings may be made directly from the pitch produced by distillation of coal tar or the pitch may be further treated in some manner to improve its temperature susceptibility. In most coal tar base linings an inert mineral filler is used to toughen the protective film.

Thermoplastic coal tar base linings are available for hot or cold application. For the former, the material consists of pitch and filler; it is melted before use and applied in the molten form. This type of product returns to its original form on cooling. When the lining is to be applied without heating, it is made by reducing the pitch to the required consistency with a coal tar distillate having the desired boiling range; filler, if used, is incorporated after the pitch has been cut back with the solvent.

Use and Summary of Properties

All thermoplastic coal tar linings are black in color. They are limited in the temperature range in which they can be used; in general, coal tar linings should not be used in contact with liquids at a temperature in excess of 120 F. The hot applied linings usually have better resistance to chemical solutions than the cold applied products. Linings made from pitch treated to improve its temperature susceptibility usually have poorer resistance to solvents and some chemical solutions than those made from untreated pitch.

The hot applied linings can be used only on metal surfaces and usually are applied over a primer composed of a coal tar distillate and a coal tar pitch base similar in characteristics to the pitch used in the lining. The characteristics of the commonly produced coal tar enamels which may be used for linings have been outlined in the report of Technical Unit Committee T-2G on "Tentative Recommended Specifications and Practices for Coal Tar Coatings for Underground Use" which appeared in CORROSION, Vol. 12, 75 (1956) Jan. Full chemical resistance is obtained with these linings immediately after cooling.

The cold applied linings can be applied over concrete, masonry, and brick, as well as metal. Generally no primer is needed. These lining materials vary in consistency from thin liquids to heavy pastes. A description of the types commonly specified will be found in the preliminary report of Technical Unit Committee T-6B on "Protective Coatings for Atmospheric Use: Their Surface Preparation and Application Requirements, Physical Characteristics, and Resistances" which appeared in CORROSION, Vol. 13, 221t (1957) Mar.

The cold applied linings require from one day to several weeks for the solvent to evaporate and the film to harden

* C. U. Pittman, Koppers Company, Inc., Verona, Pennsylvania, chairman.

TABLE 1—Physical Properties of Coal Tar Base Linings

Property	TYPE OF LINING	
	Hot Applied	Cold Applied
Thermoplastic (TP) or Thermosetting (TS)	TP	TP
Water Absorption, percent in 6 years at 25 C	0.5–0.6	.....
Water Absorption, percent in 2 weeks at 25 C	.....	<0.05
Moisture Vapor Transmission, grains/sq ft/in Hg vapor pressure difference	.....	0.045
Maximum Safe Temperature for Exposure—		
Dry conditions	120–160 F	160–220 F
Wet conditions	100–120 F	120 F
Weathering	Fair	Good
Odor	Coal Tar	Coal Tar
Dielectric Strength, volts/mil at 60 cycles	400–600	250–400

TABLE 2—Chemical Properties of Coal Tar Base Linings

MEDIA	TYPE OF LINING	
	Hot Applied	Cold Applied
Acids:		
Sulfuric, 10%	LR*	NR
Sulfuric, 50%	NR	NR
Hydrochloric, 10%	LR	NR
Hydrochloric, 20%	NR	NR
Nitric, 10%	LR	NR
Nitric, Conc.	NR	NR
Phosphoric, 10%	LR	NR
Phosphoric, 85%	NR	NR
Acetic, 10%	LR	NR
Acetic, Glacial	NR	NR
Fatty Acids	NR	NR
Water:		
Tap	R	R
Distilled	R	R
Sea	R	R
Alkalies:		
Sodium Hydroxide, 10%	R	LR
Sodium Hydroxide, 70%	NR	NR
Ammonium Hydroxide, 10%	R	LR
Calcium Hydroxide, Slaked Lime Slurry	R	R
Ammonium Salts	R	R
Oxidizing Agents:		
Concentrated Solutions	NR	NR
Dilute Solutions	LR	R
Fats and Oils:		
Mineral	LR	LR
Animal	LR	LR
Vegetable	LR	LR
Gases:		
Chlorine	NR	NR
Ammonia	LR	LR
Carbon Dioxide	R	R
Sulfur Dioxide	LR	LR
Hydrogen Sulfide	R	R
Solvents:		
Alcohols	LR	LR
Aliphatic Hydrocarbons	LR	LR
Aromatic Hydrocarbons	NR	NR
Ketones	NR	NR
Ethers	NR	NR
Esters	NR	NR
Chlorinated Hydrocarbons	NR	NR
Salts:		
Sodium Chloride	R	R
Calcium Chloride	R	R
Sodium Sulfate	R	R
Sodium Bisulfite	R	R
Sodium Carbonate	R	R
Sodium Nitrate	R	R
Alum	R	R
Sodium Sulfite	R	R
Sodium Acid Sulfate	R	R
Zinc Chloride	R	R
Sodium Metasilicate	R	R
Sodium Bichromate	R	R
Miscellaneous:		
Sodium Hypochlorite	LR	LR

* Key to letters is as follows: R = Recommended; NR = Not Recommended; LR = Limited Recommendations.

to its ultimate state where full chemical resistance is obtained. The actual time required is dependent upon such factors as coating thickness, temperature, humidity, and air movement.

Forms Available

Hot applied thermoplastic coal tar base linings are available in a range of physical properties as indicated in the report of Technical Unit Committee T-2G. However, Type 3 is most generally used, especially in water lines, because of its better temperature susceptibility. The hot applied linings are generally applied to a thickness of 1/16 to 3/32 of an inch.

The cold applied thermoplastic lining materials range from thin liquids to heavy pastes; the types commonly specified are covered in the preliminary report of Technical Unit Committee T-6B. Dry film thicknesses obtained per coat vary from about 2 mils to 18 mils with the cold applied linings. For contact with potable water or in air conditioning systems, special products should be specified, which on drying impart no taste or odor to the water or air.

Effect of Compounding

The coal tar pitch used in lining materials may be used directly or may be further treated in some manner such as digestion with coal and heavy creosote oil to improve its temperature susceptibility and reduce its brittleness; considerable variation in properties can be obtained by varying the proportions used. The impact and abrasion resistance and the resistance to cracking at low temperature can be varied somewhat by the type and amount of filler used.

Resistances

Physical properties of hot and cold applied coal tar base linings are given in Table 1. In Table 2, recommendations are made regarding the use of these materials in various environments.

Water and Moisture

Resistance of coal tar base linings to water is excellent. Water absorption is very low; hot applied linings, approximately 100 mils thick, absorb practically no moisture in 24 hours and after almost six years of immersion show an absorption of only 1.7 to 2.3 gms per sq ft or 0.5 to 0.6 percent by weight. The cold applied linings when thoroughly dry will show a slightly higher water absorption.

The moisture vapor transmission through thermoplastic coal tar linings also is very low. With the heavier types of cold applied linings the permeance of a two-coat system at a thickness of about 30 mils is generally less than 0.045 perms or 0.045 grains per sq ft per hour per inch of mercury vapor pressure difference.

The excellent resistance to water and the durability of thermoplastic coal tar base linings are attested by the fact that they have provided many years of trouble-free service on ships, floating drydocks, lockgates, tanks, water lines, penstocks, cooling towers, and sewage disposal plants.

Inorganic Acids

Hot applied thermoplastic coal tar base linings show fairly good resistance to most inorganic acids at normal atmospheric temperatures. However, they should not be recommended for continuous contact with strong acids without prior testing to determine their suitability. Usually the cold applied linings are inferior to the hot applied type insofar as resistance to acids is concerned.

Oxidizing Conditions

Thermoplastic coal tar base linings are not recommended for use under strongly oxidizing conditions.

Organic Acids

Themoplastic coal tar base linings are not recommended for use in contact with strong solutions of aliphatic acids or with fatty acids.

Alkalies

Thermoplastic coal tar base linings show satisfactory long-term resistance to alkalies at normal atmospheric temperatures. However, they should not be recommended for continuous contact with high concentrations without prior testing to determine their suitability. Resistance to continuous immersion in alkaline salts is good.

Salt Solutions

Thermoplastic coal tar base linings have shown good long-term resistance to salt solutions of various kinds even when the concentrations are high.

Solvents

Generally speaking, thermoplastic coal tar base linings have limited resistance to solvents due to the gradual extraction of plasticizing oils.

Oils

The resistance of Type 1 hot applied and medium viscosity, medium duty cold applied thermoplastic linings to mineral, animal, and vegetable oils is generally satisfactory. The other types of hot and cold applied linings have poor resistance to these oils. A test should be made prior to use to determine the suitability of the lining selected because of the possibility of imparting color to some oils.

Temperature Limitations

In contact with liquids, thermoplastic coal tar linings should not be used at a temperature above 120 F. For atmospheric corrosion resistance some types will withstand much higher temperatures.

Toxicity

Although not considered to be toxic, thermoplastic coal tar base coatings are not recommended for use in contact with foods because they may impart taste and odor. Some types of coal tar base linings are used in water lines and tanks and impart no taste or odor except on prolonged standing with no flow.

Adhesion and Abrasion Resistance

On properly prepared metal surfaces the adhesion of all types of thermoplastic coal tar linings is excellent; they have far above average resistance to undercutting. Cold applied linings also have excellent adhesion to concrete and masonry surfaces. These linings are not recommended where a high degree of resistance to abrasion is required.

Hardness

The hardness of the various types of thermoplastic coal tar base linings varies widely at normal atmospheric temperatures; no data on the actual hardness are available at the present time. The hardness of any coal tar base lining will vary greatly with temperature. Generally, in common with all thermoplastic

materials, these linings are hard and somewhat brittle at low temperatures and become softer as the temperature is raised.

Weathering and Aging

Thermoplastic coal tar base linings usually are not recommended for atmospheric exposure since they tend to alligator and crack on prolonged exposure to direct sunlight although they still give protection. At atmospheric temperatures, the coatings show very gradual hardening; in contact with water or solutions this hardening takes place very slowly, if at all.

Electrical Properties

Thermoplastic coal tar base linings have a dielectric strength of 400-600 volts per mil.

Application

Hot applied thermoplastic coal tar base linings are supplied as a solid which must be broken into lumps, melted, and applied while molten. The recommended procedure for melting will be found in the report of Technical Unit Committee T-2G on "Tentative Recommended Specifications and Practices for Coal Tar Coatings for Underground Use."

Cold applied thermoplastic coal tar base linings are supplied in different consistencies which vary from a thin liquid to a heavy paste, depending upon the film thickness to be applied. In most cases, the solvent should evaporate from these coatings before they are ready for use.

Coverage

Coverage will depend upon the film thickness desired. The hot applied thermoplastic linings are usually applied to a thickness of 1/16 to 3/32 inch. The cold applied thermoplastic products have recommended application rates varying from 400 to 50 sq ft per gallon.

Surface Preparation

Generally it is recommended that surfaces to which thermoplastic coal tar linings are to be applied should be sand or grit blasted to a uniform gray surface. This practice should be followed especially when a hot applied coal tar lining is used. Because of their excellent wetting qualities, most cold applied coal tar base coatings can be applied with relatively little surface preparation if adhesion is the only consideration; generally, the surface should be free of dirt, grease, and loose rust and mill scale. Since the life of any coating, especially in an aggressive environment, is dependent primarily upon the surface preparation, longer service will result when the surface is sand or grit blasted.

Priming

With a hot applied thermoplastic coal tar lining, priming is necessary to obtain satisfactory adhesion. The primer used should be that specified by the manufacturer for use with the lining to be applied. The cold applied coatings generally require no primer.

Application Methods

Hot applied thermoplastic coal tar linings are applied to the interior of lengths of pipe over the dry primer by the spinning method using either a trough or retractable weir to spread the material. On the exterior surface of pipe, this type of coating is applied over the dry primer in a rolling rig, end feed machine, or line traveling machine (usually with an outer wrap of coal tar saturated asbestos felt and/or Kraft paper.) On odd shapes of flat surfaces, the lining is applied over the dry primer by hand-daubing in shingle fashion using a Tampico dauber or on horizontal surfaces with a glass mop. The primer is applied by spray, brush roller, or rug, depending upon the type of surface to be coated. After application of the lining, it is tested for continuity by the use of a holiday tester with 10,000-15,000 volts across the terminals. All voids are cut out and patched with fresh material.

All of the cold applied thermoplastic coal tar linings can be applied by brush, spray or roller. The thin coatings can be applied with conventional spray equipment or also by dip. The heavier coatings can be sprayed only by using a heavy duty pump and a larger diameter hose (3/4-1 inch ID) than is employed with conventional spray equipment to carry the material from the container to the spray gun; these coatings are customarily mixed with a mechanical agitator to ensure uniformity before application. A larger nozzle (nozzle is sometimes removed) and tip and a higher atomization air pressure (50-90 psi) are required than with conventional coatings for proper application of these products. Usually only two or three coats are applied to obtain the desired dry film thickness. Drying time between coats will vary usually between 16 and 96 hours, depending upon the temperature, humidity, and air velocity over the coated surface. To ensure continuity of the coating after drying, it is desirable to test it with a holiday detector using 100 volts per mil across the leads; the type of holiday detector used will vary with the coating thickness. All voids should be cut out and patched with the same material.

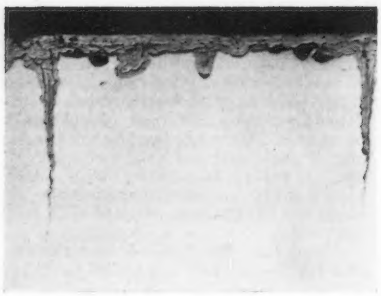


Figure 1—Stress corrosion cracks in a 9 percent nickel steel beam specimen (fiber stress 70,000 psi) after 306 days in tap water saturated with hydrogen sulfide. Original magnification, 100X; actual magnification after reduction for engraving purposes, 65X. Unetched.

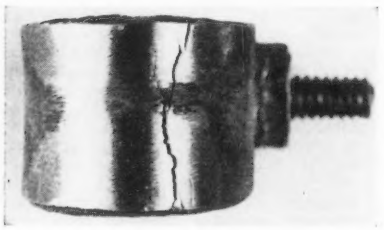


Figure 2—Cracks in cathodically pickled U-bend specimen of 9 percent nickel steel. Photograph is taken from Reference 2 (Prange).

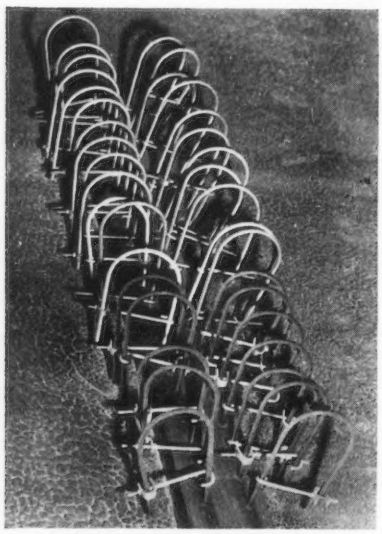


Figure 3—Type of U-bend specimens used by Bloom[3] for stress corrosion cracking tests of hardenable stainless steels.

The Behavior of Steels in Hydrogen Sulfide Environments*

By L. W. VOLLMER

Abstract

Spontaneous cracking of steels in deep high-pressure condensate wells producing gas containing hydrogen sulfide has been a subject for considerable investigation during the past seven or eight years. This paper presents: (1) a definition and possible mechanisms for sulfide-stress cracking of steels, (2) the methods currently being used to establish the susceptibility of steels to this phenomenon, (3) a brief summation of the significant developments from research on the problem, and (4) the measures that are currently indicated to minimize the possibilities of such failures in steel equipment.

The term "sulfide-stress cracking" is preferred to the commonly used "sulfide corrosion cracking" since the phenomenon is stress dependent.

The susceptibility of most constructural steels to sulfide-stress cracking can be minimized, if not eliminated, by appropriate heat treatment which must include tempering at a temperature not less than 1150 F and by limiting the maximum mechanical properties to predetermined levels. When the use of high strength metals is unavoidable, certain nonferrous alloys, which thus far have indicated a high degree of insensitivity to the phenomenon, are suggested.

3.2.2

Introduction

THE ERRATIC behavior of steels in corrosive hydrogen sulfide environments is not a new problem to the oil production industry. But despite long experience in sour heavy crude oil production, the full damaging effects of hydrogen sulfide were not realized until production from deep, high pressure sour condensate wells began.

During the past seven or eight years, considerable research has been conducted to develop a better understanding of and means for avoiding the phenomenon that was initially called sulfide corrosion cracking. The term "sulfide-stress cracking" is considered more appropriate by the author, since stress is one of the major factors on which the phenomenon depends, and there is some question as to the role played by corrosion other than generation of nascent hydrogen.

The literature relating to sulfide-stress cracking is now so voluminous that a comprehensive review of it will not be attempted in this paper which is limited to a discussion of: (1) the definition and possible mechanisms for sulfide-stress cracking of steels; (2) the methods currently being used to establish the susceptibility of steels to this phenomenon; (3) a brief summation of the significant developments from research on the problem; and (4) the measures that are currently considered to be indicated by these developments, for minimizing the possibilities of such failures in the equipment for high pressure sour condensate wells.

Definition and Possible Mechanisms

Sulfide-stress cracking is the spontaneous fracturing of steel subjected simultaneously to a corrosive hydrogen sulfide-aqueous medium and a static stress less than the tensile strength of the metal. The stress may be, and usually is, less than the yield strength. The primary fracture is brittle in nature. When a complete break occurs in a tube, for example, the entire fracture may be brittle, or part of it may show definite plastic deformation; this indicates that either the steel reacted variably to the environment (suggesting inhomogeneity in the metal) or other conditions necessary or contributing to sulfide-stress cracking were not uniform.

The mechanism of sulfide-stress cracking is still in controversy. Initially it was thought by some, including the author, that true stress corrosion cracking was responsible for the phenomenon,[1] but it was conceded early in the investigation of the first well equipment failures,[2] that hydrogen embrittlement of the steel might be an important contributory factor.

There is increasing evidence that nascent hydrogen absorbed by steel under stress may be the major, if not the sole, factor responsible for the failure process when it occurs in very short periods of time. It is true that corrosion of the metal by aqueous hydrogen sulfide is the source of the nascent hydrogen absorbed by the steel. It is also a fact, however, that steel can be made to fail in an identical manner without any apparent corrosion when the steel, subjected to sufficient stress in the elastic range, is charged with hydrogen by cathodic means.[2,3] Of course corrosion can contribute to the failure process by developing sites (pits) for concentration of stresses so that fracturing may occur under circumstances where the failure would not have occurred in steel charged with hydrogen if the corrosion had not taken place. However in this case the influence of corrosion is ac-

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TABLE 1—Sulfide-Stress Cracking Data on API Grade N-80 Tubing Steels

Specimen	Average Yield Strength	Tensile Strength	Hardness R_c	Prestress psi	Applied Stress psi	Time to Failure Days	Number of Cleanings
Steel A[1]	94,200	139,900	30.0	139,900	73,600	0—16 hours	0
	94,200	.....	28.0	117,000	73,600	0—16 hours	0
	94,200	139,300	30.0	139,300	64,400	2—3	1
	94,200	.....	28.0	118,800	64,400	684[3]	80
Steel B[2]	98,700	135,300	28.0	135,300	78,400	76	11
	98,700	.....	28.0	116,800	78,400	592[3]	80
	99,600	135,300	28.0	135,300	68,600	592[3]	80
	99,600	.....	27.0	117,800	68,600	592[3]	80

[1] Composition: C—0.41 percent, Mn—1.83 percent, Mo—0.22 percent
[2] Composition: C—0.40 percent, Mn—1.65 percent, Mo—0.14 percent
[3] Removed from test.

About the Author

L. W. VOLLMER is Director of the Materials Engineering Division, Gulf Research and Development Company, Pittsburgh, Pa. He is a graduate of Penn State University. Mr. Vollmer was a Fellow at Mellon Institute from 1926 to 1930. In addition to NACE he is a member of ASM, AIME, and API.

tually physical rather than chemical in nature.

True stress corrosion cracking of steel in an aqueous hydrogen sulfide environment does seem possible as shown in Figure 1. However the time to failure by this process is generally extended and usually there are multiple cracks, in contrast with the single crack that is characteristic of sulfide-stress cracking. Possibly cracking of steel in sulfide environments is not a single mechanism for failure but may be (1) true stress corrosion cracking, (2) the effects of nascent hydrogen absorbed by steel under stress, or (3) a combination of both.

The degree to which the two basic processes influence failure and the time to failure are considered to be governed by the rate of hydrogen absorption by the steel and the *total* tensile stress in the steel. When time to failure is very short—a matter of hours or a few days—it is believed that the failure is induced by the effects of absorbed hydrogen and stress. If the time to failure is long—months or years—the failure process may be true stress corrosion cracking. Combinations of the two processes would induce failures at intermediate time intervals depending on which process was dominant.

Most of the equipment failures that have been experienced in sour condensate well service have occurred in very short periods of time, which, on the basis of the foregoing, would indicate that they were the result of absorbed hydrogen and stress. The manner in which hydrogen absorbed by steel under stress decreases the load carrying capacity of steel as yet has not been explained. Although many theories have been advanced,[4-7] none has been proved. When steel fractures in a brittle manner, as a consequence of hydrogen absorption, at stresses well below the yield strength, it might be reasoned that either the tensile properties of the steel are depreciated by the absorbed hydrogen, or in some manner the absorbed hydrogen becomes a source of additional internal stress which added to the applied stress equals the ultimate strength of the steel.

de Kazinczy[8] has shown that hydrogen flow through an annealed 0.13 carbon steel cylinder subjected to axial tensile stress in the elastic range increased almost proportionately to the stress (0.25 percent for each 1500 psi), as a consequence of increased solubility of hydrogen in the lattice. When specimens were subjected to plastic deformation (1.0 to 7.2 percent elongation), the flow of hydrogen through the cold worked steel under stress increased considerably more than would be expected in the case of homogeneous lattice diffusion.

de Kazinczy postulated that plastic deformation creates zones in the metal in which the external (applied) stress is multiplied. These zones may be comparatively narrow with a high stress concentration factor. In these zones the activity coefficient of the hydrogen would be decreased, which, especially in the presence of high external stresses, would result in inhomogeneous distribution of flow through the specimen. Hydrogen would pass more readily through the highly stressed zones. If it is assumed that such zones are located along slip planes or other deformation planes, the increased flow could be explained by this hypothesis. This theory might be extended to the situation where, under the combined applied and internal stresses, distortion at imperfections (dislocations) in the crystal lattice becomes sufficiently great to permit association of the absorbed atomic hydrogen to molecular hydrogen. Accumulation of molecular hydrogen at these submicroscopic sites might then be the source of internal stress which, in combination with the applied and initially present internal stresses, is sufficient to cause brittle fracture at the normal tensile strength of the steel.

The four major factors on which the sulfide-stress cracking process depends are: (1) absorption of a sufficient quantity of nascent hydrogen, (2) a *total* tensile stress of sufficient or critical magnitude, (3) a susceptible metallurgical condition in the steel, and (4) time. In other words, a critical combination of these four factors is required for sulfide-stress cracking of steel. If any of these factors is absent, or is of insufficient magnitude, failure will not occur.

These major factors are also interdependent. For instance, if the total stress is very high, the quantity of absorbed hydrogen required for failure is less than in the case where the stress is relatively low but at or above a critical level. If the metallurgical condition of the steel is such that the steel is highly susceptible to the phenomenon, both the quantity of absorbed hydrogen and the applied stress that will induce cracking are lower than when the steel has low susceptibility. Time for failure to occur is governed by the combined effect and magnitude of the other three factors. In addition to these four major factors, there are contributory influences such as prior plastic deformation of the metal, corrosion products, and temperature.

Methods of Testing

It is considered that the sulfide-stress cracking problem is a special case of the hydrogen-in-steel problem to the extent that the nascent hydrogen available for absorption by the steel is limited by the reaction between the hydrogen sulfide corrodent and the metal. This should be emphasized because it has an important bearing on the methods that may be utilized for determining the susceptibility of steels to the sulfide-stress cracking conditions encountered in sour condensate production and associated operations. It should be emphasized also that the total stresses to which the steel is subjected must be considered. This has been a complicating matter in reliably evaluating steels for sulfide service.

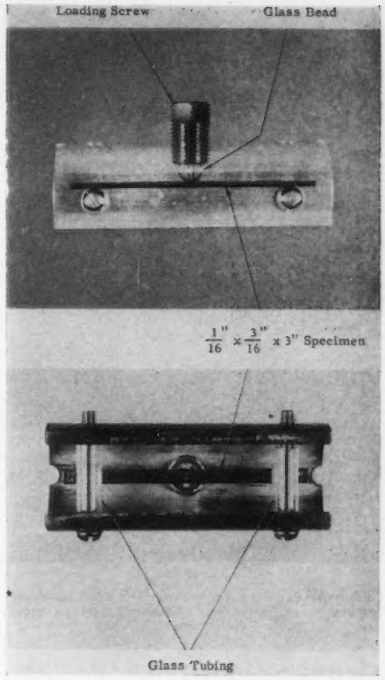

Figure 4—Laboratory test holder used by Fraser and Treseder[10] for evaluation of resistance of steels to sulfide-stress cracking. Top photograph is phantom view of assembled holder and specimen. Bottom photograph shows view of holder from bottom.

Figure 5—Method of applying bending load to beam specimen for sulfide-stress cracking tests. Photographs are from reference 2 (Vollmer, Bowers, McGuire, Wiehe.)

Stress that is applied to a steel section can be established with accuracy, but the magnitude of the residual or internal tensile stress present in steel is virtually indeterminate. Nevertheless useful evaluation of steels for sulfide service is still possible, provided the procedures do not involve abnormal alterations in the metal to be tested and large deviations from corrosive conditions encountered in service. The several evaluation methods currently employed are basically the same in that the specimen of metal under test is subjected simultaneously to a static stress and an aqueous hydrogen sulfide corrodent.

U-Bends

One method makes use of U-bends, two types of which are shown in Figures 2 and 3 (Prange[2] and Bloom[9]). The specimens are usually preformed before heat treatment and then subjected to stress by pulling together the legs of the U with a nut and bolt, or clamp. In this type of specimen the magnitude of applied stress is not always known and

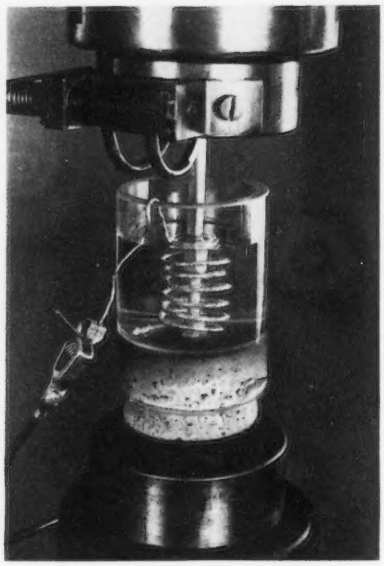

Figure 6—Experimental set-up for sulfide-stress cracking or cathodic embrittlement tests on steel under tension.

Figure 7—Crack in martensitic structure of a test beam of API N-80 tubing steel with high manganese content and Rockwell C 28 hardness. Original magnification, 1000X; actual magnification after reduction for engraving purposes, 660X. Etchant: nital plus picral.

sometimes the specimen is stressed beyond the yield strength of the steel. Also any damage to the steel as a consequence of the extensive plastic deformation involved in forming the U-bend not subsequently heat treated remains an unknown and undoubtedly important factor. Although quantitative data can be obtained with this type of specimen, the test conditions are difficult to control and the effects of plastic deformation of the metal cannot be established with any degree of precision.

Small Beams

A second method of testing makes use of small beams loaded to a predetermined amount of bending in an appropriate fixture. Examples of these are shown in Figures 4 and 5. This technique is considered basically sound, provided that the maximum fiber stress developed in the beam specimen is less than the yield strength of the steel. If the beam specimen should plastically deform under the test load, the applied stress decreases to a value difficult to establish and a new factor, plastic deformation of an indeterminate amount, has been introduced.

One major disadvantage of the beam method of testing is the large stress gradient across the section. Only the fibers of one surface of the beam are subjected to the maximum tensile stress intended, and since sulfide-stress cracking is so vitally dependent upon stress, this method may not be as discriminating as desired, particularly for steels that have relatively low susceptibility to sulfide-stress cracking.

The steels for oil field equipment, particularly tubular products, are very frequently plastically deformed during fabrication; also plastic deformation occurs in service for many well known reasons such as bending pipe and tonging joints. Since plastic deformation influences the response of many steels to sulfide-stress cracking, known amounts of plastic deformation should be developed in test specimens. A convenient method of accomplishing this is to subject a blank for the test specimen to known amounts of stress in the plastic range up to the ultimate strength of the steel under test. The blank is then machined to desired final dimensions.

Special Equipment

A third method requires small tensile specimens which are subjected to tensile loads in appropriate equipment that provides for exposure of the test section of the specimen to the corrodent. Figure 6 shows a tensile machine being used to apply the load, but any desired means may be employed such as bolt type specimens in an appropriate frame (utilizing nuts and an extensiometer for application and control of the stress[11]), or by dead weight loading in a device such as is used for creep testing.[3,9] This type of testing is recommended because it permits uniform loading in tension across the section of the test specimen, and avoids the complex stress patterns inherent in the previous two methods.

The corrodent used for the evaluation of steels should closely approximate the corrosive conditions encountered in service. Since sulfide-stress cracking occurs very rapidly as a general rule, it is unnecessary and unwise to accelerate testing by artificially increasing the corrosivity of the environment.

Cathodic charging of hydrogen into steel under stress presents interesting possibilities as a means for evaluating the susceptibility of steels to sulfide-stress cracking. But here again, the conditions under which the steel is cathodically charged with hydrogen should be electrochemically equivalent to those existing in hydrogen sulfide systems encountered in service. If it is assumed that the initial corrosion rate of steel in a relatively fresh water-hydrogen sulfide system is 175 mdd (32 mils/year), the equivalent current density would be 0.45 ma/sq inch. When current densities greatly in excess of this are used, abnormally large quantities of hydrogen are absorbed by the steel, and the reaction of the steel may be not at all representative of the reaction to the sulfide environments involved in sour condensate well service. The electrolyte commonly used for cathodic charging work is dilute sulfuric acid (4 to 5 percent) to which is added a small amount of "poison" (arsenic trioxide or carbon disulfide) to promote hydrogen absorption as does hydrogen sulfide in solution.

Summary of Significant Developments

Early in the research work on the sulfide-stress cracking problem it became evident that steels having a hardness of Rockwell C 20 or less are virtually immune to the phenomenon, provided they had not been drastically cold worked.[2] When the hardness exceeds about Rockwell C 30, all ferritic steels tested thus far show a high degree of susceptibility to cracking regardless of the amount of prior plastic deformation. However plastic deformation will markedly increase the susceptibility of such steels. In the hardness range Rockwell C 20-30, the susceptibility of steels to sulfide-stress cracking may be highly variable. This is to be expected since hardness is a rather crude parameter of the mechanical and metallurgical properties of steel.

Steels having different or mixed metallographic structures may have either approximately the same or decidedly different tensile properties. Much of the experimental work accomplished thus far has been directed toward determining, by one or more of the testing techniques previously discussed, those metallurgical conditions of steels in the hardness range Rockwell C 20-30, and the limits of applied tensile stresses that would minimize or avoid failure by sulfide-stress cracking. The following are the most significant observations indicated by this work and some of the evidence in support of them:

Susceptibility To Cracking

(a) Virtually all ferritic steels can be made susceptible to sulfide-stress cracking. Sensitivity of steel is ascribable at least in substantial part to the metallurgical constituent martensite and some of the structures obtained by tempering martensite. Figure 7 shows a microscopic crack induced by sulfide-stress cracking in a partly martensitic structure found in the steel commonly used for API Grade N-80 pipe (0.41 carbon, 1.83 manganese, 0.22 molybdenum); the hardness was Rockwell C 28. A beam specimen of this steel failed in less than 16 hours at 73,600 psi applied fiber stress when immersed in tap water saturated with hydrogen sulfide. In contrast, another beam of the same type of steel which was also Rockwell C 28 but did not contain martensite, did not fail at a fiber stress of 78,400 psi after 592 days in the same corrodent.

Critical Stress

(b) Apparently there is a critical stress at and above which a sensitive steel will fail in a sulfide corrodent. It will be noted in Table 1 that the sensitive N-80 tubing Steel A fractured in less than 16 hours at 73,600 psi when prestressed at 117,000 psi, but did not fail in 684 days at 64,400 psi after prestressing at 118,800 psi. The less sensitive Steel B withstood 78,400 psi applied stress under the same test conditions, indicating a critical stress at least 5000 psi higher than that of Steel A.

Plastic Deformation

(c) Plastic deformation (as in cold straightening tubing) will increase the sensitivity of a susceptible steel and lower the critical stress level. Prestressing at 139,900 psi caused sensitive N-80 Steel A (Table 1) to fail in 2-3 days at 64,400 psi applied stress, but at 118,800 psi prestressing failure did not occur in 684 days at the same applied stress. Borderline steel may be sensitized by severe cold work as indicated by the data for Steel B in Table 1, prestressed at 135,300 psi. This steel failed in 76 days under applied stress of 78,400 psi; when the prestress was reduced to 116,800 psi, Steel B did not fail at 78,400

psi applied stress even after 592 days exposure to the corrodent. It should be noted that corrosion products were removed (mechanically) at regular intervals; this is necessary because the corrosion products may protect the steel thereby masking susceptibility.

Chemical Composition of Steel

(d) The chemical composition of steel appears to influence sensitivity to sulfide-stress cracking only insofar as composition determines the hardenability of steel. Plain carbon steels are low in hardenability and therefore do not readily develop metallurgical structures that are susceptible to the cracking phenomenon. As the hardenability of steel is increased by alloy additions to provide higher mechanical properties, unfavorable structures will more readily develop and more complete thermal processing is necessary to avoid susceptibility.

Total Stress

(e) Since sulfide-stress cracking is a stress dependent phenomenon, the *total* stress to which the steel is subjected must be considered. This includes the applied tensile stress and the residual tensile stresses resulting from phase transformation during the heat treatment, thermal effects, and cold deformation during fabrication and service.

Hydrogen Charging

(f) As previously stated, steel can be made to crack without any apparent corrosion when the steel under sufficient stress within the elastic range is charged with hydrogen by cathodic means. The response of steels to these conditions appears to be exactly the same as that developed in aqueous hydrogen sulfide.

Further evidence of a "critical stress" is shown by the data in Table 2. Small diameter tensile specimens of API N-80 type steel, properties of which are given in Table 3, were tested in the equipment shown in Figure 6. The current density was greatly in excess of that previously indicated as representative of a severely corrosive hydrogen sulfide environment but was used in the course of developing a susceptibility evaluation test method.

Spontaneous cracking occurred between 1 and 2 hours when the applied stress was 81,200 psi; at 71,100 psi applied stress the time to failure increased to approximately 3 hours minimum and 12 hours maximum. A further reduction in applied stress to 60,900 psi appears to have avoided spontaneous cracking since failure did not develop in approximately 90 hours, at which time the experiment was terminated.

In contrast with this, the much greater susceptibility of a precipitation hardening stainless steel (properties of which are given in Table 3), is shown by the data in Table 4. Spontaneous fracturing occurred in this steel in 0.5 minute at 136,000 psi applied stress and even at 42,000 psi failure developed in 141 minutes. Cracks developed throughout the entire test section of the specimen of this steel as shown in Figure 8. The fracture face, Figure 9, exhibited so-called "fish eyes" which indicate that the failure probably originated internally rather than on the surface of the specimen.

The same relative difference in the susceptibility of the N-80 tubing steel and the precipitation hardening stainless steel was indicated by beam tests. At applied fiber stresses equivalent to 80 percent of the yield strengths, the hardened 322 stainless steel fractured within 16 hours; the N-80 steel beam specimen did not fail in 1176 days in aqueous hydrogen sulfide. This is particularly noteworthy since it supports the contention that cathodic charging of steel with hydrogen at excessive current densities can give misleading results, at least from a practical engineering standpoint.

The critical stress concept suggests that when steel under tension is charged with hydrogen, there may be an applied tensile stress level at which the original load carrying capacity of the steel may undergo a marked reduction before actual fracturing of the steel occurs. The data in Table 5 seem to indicate that there may be some basis for this concept. The API N-80 tubing steel (Table 3), which had an original ultimate strength of 124,900 psi, showed only slight, if any, reduction in strength when charged with hydrogen for 420

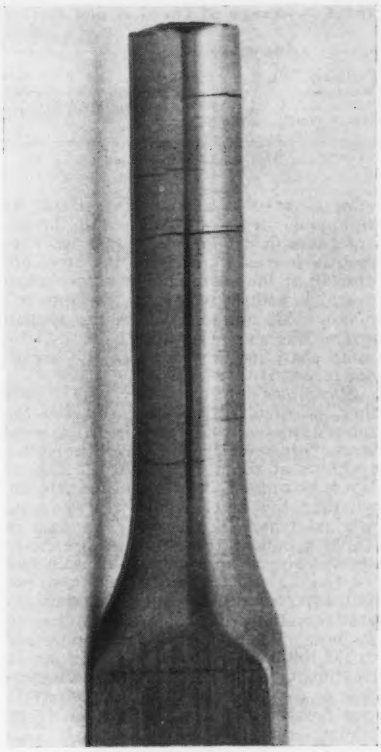

Figure 8—Cracks in gage length of Type 322 stainless steel cathodic embrittlement specimen which failed after 4.5 minutes at stress of 136,000 psi (80 percent of yield strength).

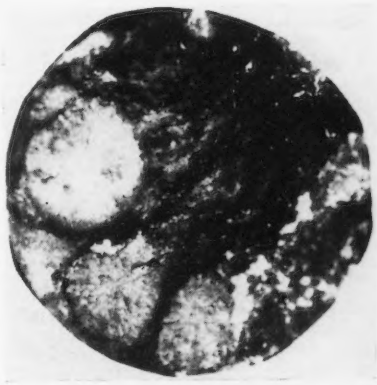

Figure 9—Fracture face of Type 322 steel cathodic embrittlement specimen which failed after 4.5 minutes at stress of 136,000 psi (80 percent of yield strength.)

TABLE 2—Effect of Applied Tensile Stress on Cathodic Embrittlement of API N-80 Tubing Steel

Applied Tensile Stress (psi)	Percent of Yield Strength	Time to Failure (minutes)
81,200	80	65-101
71,100	70	195-732
60,900	60	No failure; 5,340 minutes

Specimen—0.125 inch diameter; Current Density—80 ma/sq inch; Electrolyte: 5% H_2SO_4 with 25 mg/liter As_2O_3

TABLE 3—Properties of Steels Used in Cathodic Embrittlement Tests

Steel Type	Tensile Strength (psi)	Yield Strength (psi)	Hardness (R_c)
API Grade N-80 0.47 C, 1.59 Mn, 0.23 Mo	124,900	98,000	24—26
322 Stainless Steel 0.07 C, 17.0 Cr, 7.0 Ni, 0.70 Ti, 0.20 Al	223,000	170,000	44—46

Note: Test Section—0.125 inch diameter x 0.625 inch.

TABLE 4—Effect of Applied Tensile Stress on Cathodic Embrittlement of Stainless Steel 322

Applied Tensile Stress (psi)	Percent of Yield Strength	Time to Failure (minutes)
136,000	80	0.5
119,000	70	1.5
85,000	50	19.0
42,500	25	141.0

Specimen—0.125 inch diameter; Current Density—80 ma/sq inch; Electrolyte: 5 percent H_2SO_4 with 25 mg/liter As_2O_3

TABLE 5—Effect of Applied Stress and Constant H^+ Charging Time on Ultimate Strength of API N-80 Tubing Steel

Applied Stress (psi)	H^+ Charging Time (min)	Ultimate Strength (psi)
0	0	124,900
0	420	121,000
60,900	420	96,800
71,100	420	94,500

Specimen—0.125 inch diameter; Current Density—80 ma/sq inch; Electrolyte: 5 percent H_2SO_4 with 25 mg/liter As_2O_3

TABLE 6—Effect of Aging on Recovery of Ultimate Strength of API N-80 Tubing Steel Cathodically Embrittled Under Stress

Applied Stress (psi)	H^+ Charging Time (min)	Aging Treatment	Breaking Stress (psi)
0	0	None	124,900
0	420	None	121,000
0	420	16 hr—R.T. + 4 hr—350 F	124,000
71,100	420	None	94,500
71,100	420	16 hr—R.T. + 4 hr—350 F	106,000

Specimen—0.125 inch diameter; Current Density—80 ma/sq inch; Electrolyte: 5 percent H_2SO_4 with 25 mg/liter As_2O_3

TABLE 7—Range of Chemical and Mechanical Properties of Six Heats of 3½ Inch API N-80 Tubing*

Carbon	0.41—0.44	Tensile strength (psi)	107,500—118,300
Manganese	1.46—1.60	Yield strength (psi)	82,100—89,900
Silicon	0.20—0.24	Elongation (% in 2 in.)	19—27
Molybdenum	0.19—0.23	Hardness—R_c	18—21

* Normalized—1550 F; Tempered 1175 F.

minutes without any applied stress. At an applied stress of 60,900 psi the breaking strength dropped to 96,800 psi. Previously it was shown that the steel did not fail at the same applied stress when charged with hydrogen for approximately 5400 minutes. When the applied stress was increased to 71,100 psi the same charging time reduced the breaking strength to 94,500 psi.

Specimens of the same steel were then charged with hydrogen for the same time with and without applied stress, after which they were aged for 16 hours at room temperature, followed by 4 hours at 350 F to determine whether the steel would recover its original tensile properties. The data in Table 6 indicate that in the absence of applied stress, hydrogen absorption had little or no effect on the breaking stress, and after aging the ultimate strength was essentially the same as the original strength. When the steel was stressed to 71,100 psi followed by the aging treatment, only approximately 38 percent of the decrease in ultimate strength was recovered indicating that some permanent damage had occurred. This seems to support the hypothesis that hydrogen is trapped in the molecular state at sites in the lattice distorted by the applied stress, thereby inducing additional internal stress which reduces the amount of applied stress necessary for tensile failure.

Means for Minimizing Sulfide-Stress Cracking Failures

A consideration of all of the information currently available on sulfide-stress cracking leads to the opinion that the following measures are indicated for preventing, or at least minimizing equipment failures in wells producing sour condensate fluids.

(a) Since martensite and some of the metallographic structures obtained by tempering martensite are importantly involved in the sulfide-stress cracking process, obviously it is essential that such structures be avoided by appropriate heat treatment. The metallographic structure and mechanical properties of steels for sulfide service must be limited. The steel commonly used for API N-80 tubing and casing has an analysis that will permit the development of the required mechanical properties by the simple normalizing heat treatment. However the range of chemistry is such that unfavorable structures can develop in the steel so heat treated. Even though the analysis of the steel was adjusted so that these structures should not develop in normal processing, segregations of alloy constituents may locally increase the hardenability of the steel so that sensitive structures will develop. This very probable circumstance can be avoided by normalizing the steel as usual followed by tempering at a temperature not less than 1150 F.

As a means for providing an adequate margin of safety, the yield strength of N-80 tubing and casing should be limited to 90,000 psi maximum. The range of properties for API N-80 tubing that was produced under these requirements from 6 heats of steel are given in Table 7. Test lengths representing the beginning, middle, and end of the continuous tempering heat treatment of four heats were used for laboratory susceptibility tests. No failures have been experienced in any of the beam specimens of these steels, prestressed to the ultimate strength and subsequently loaded to the maximum fiber stress equivalent to 80 percent of the yield strength followed by exposure to aqueous hydrogen sulfide for 200-500 days. Although the service experience with this tubing has been rather short, no failures have occurred. As more information on the general subject is developed, it is probable that the limit on maximum yield strength can be raised. If steels having an analysis other than that commonly used for N-80 tubular products are contemplated, they should be evaluated by thorough laboratory tests to establish the heat treatment necessary to impart maximum resistance to the cracking phenomenon.

(b) Every reasonable effort should be made to minimize stresses in all equipment and especially in tubing and casing. An integral joint of the shouldering type for tubing is considered preferable to regular API coupled joints because the hoop stresses in such joints are substantially less.

(c) If the producing formation is to be acidized, an internal plastic coating on the tubing is considered advisable. The hydrochloric acid used for acidization frequently contains an arsenic inhibitor which is not completely effective, and it is possible that steel which may still retain some susceptibility to the cracking phenomenon may be damaged or conditioned for rapid failure when production is resumed. The removal of protective sulfide films from the steel surface by the acid will expose bright metal to the full damaging effects of the sour well fluids.

(d) Since fully heat treated N-80 casing is not yet available, it is advisable to use packers to exclude sour fluids from the annulus between the tubing and the oil string of casing; the tensile stresses in the upper joints of the tubing string should be minimized by setting down on the packers as much of the weight of the tubing string as is practicable.

(e) Deep tong marks in tubing and casing should be avoided since the drastic cold deformation may induce susceptibility to the cracking phenomenon in steel that otherwise would exhibit little or no sensitivity.

(f) Welded connections regardless of the type of steel involved should be avoided as much as possible because voids in the welds will function as traps into which hydrogen absorbed by the steel will diffuse, associate to molecular hydrogen, and accumulate to produce high stresses that may cause failure. When welding cannot be avoided, every precaution should be taken to prevent rapid cooling or a quenching action that will develop sensitive structures in steel, and all welds should be heat treated to reduce internal stresses to a low order of magnitude.

(g) When high strength materials are required for equipment such as pressure controls, nonferrous alloys such as K Monel, Inconel, and the Hastelloys are advisable. Alloys of this type thus far have indicated a high degree of insensitivity to sulfide-stress cracking. If the use of high strength steels that are certain to be sensitive to the cracking phenomenon cannot be avoided, nonporous nickel plating of the ductile type is effective so long as the plating remains intact.

Although the sulfide-stress cracking problem is far from being fully resolved, it is believed that judicious application of the present knowledge will greatly reduce the hazard and incidence of equipment failures in the handling of sour condensate fluids.

Acknowledgment

The author acknowledges the collaboration of his associate W. J. McGuire in much of the work covered by this discussion.

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Any discussions of this article not published above will appear in the December, 1958 issue

Surface Area Relationships In Polarization and Corrosion*

By MILTON STERN

Abstract

The polarization behavior of surfaces containing regions which exhibit different overvoltage parameters for the same reaction are described. Also, the effect of cathode area fraction on corrosion potential and corrosion rate is considered for a corroding surface controlled by activation polarization. It is shown that the corrosion potential and corrosion rate are most sensitive to area changes when the surface is largely cathode or anode. The corrosion current reaches a maximum when the surface is equally divided into anodic and cathodic regions. 3.6.8

Introduction

ELECTROCHEMICAL measurements often are conducted on surfaces which are not homogeneous in nature. Thus, it is possible to have an electrochemical oxidation or reduction proceed on a surface which contains regions with different activation overvoltage parameters for the same reaction.

An example of such a situation would be a study of hydrogen evolution kinetics on a zinc surface containing regions which are amalgamated. Actually, one usually works with such non-homogeneous surfaces whether or not this is his intent. This is true because even the purest metals show different overvoltage behavior for different crystallographic planes. Also, grain boundaries in metals would not be expected to behave the same as grain centers.

Perhaps the most serious cause of inhomogeneity results from deposition of traces of contaminants from the solution onto the surface. It is important to understand the effect on measured overvoltage parameters of measurements with such surfaces. One of the purposes of this work is to describe the behavior of such systems in a quantitative manner.

When one considers a corroding metal containing regions which function predominantly as sites for reduction or oxidation, then the fraction of the surface which is anode or cathode plays an important role in determining its electrochemical behavior. In particular, the corrosion potential and corrosion rate are markedly influenced by the area ratio. Quantitative relationships can be derived which describe the change in corrosion potential or corrosion rate as a function of area fraction for systems which are activation controlled. These equations and their significance are discussed below.

Surfaces with Regions Exhibiting Different Overvoltage Behavior for the Same Reaction

The basis for description of such systems is dependent upon the assumption that the total current one measures in polarizing a surface to a given fixed potential is the sum of the individual currents which flow to the separate regions which comprise the surface. For cathodic polarization, this is nothing more than considering that the total rate of reduction is equal to the sum of the individual rates of reduction on all the regions of the surface at constant potential.

In order to prove this experimentally, it is necessary to study a composite surface with known area relationships and known overvoltage parameters. Such a system is not easily designed. However, in some previous work[1], it was noticed that both titanium and Type 316 stainless steel in nitrate inhibited solutions of ferric and ferrous chloride exhibited potentials which were very close to the reversible ferric-ferrous potential of the solution. In addition, the exchange current density on a titanium surface was considerably less than that which exists on a stainless steel surface. Thus, composite electrodes of these two materials provide an ideal system to test the above assumption, since they both exhibit essentially the same potential before coupling and local galvanic effects need not be considered. Thus, an experiment was designed where various area ratios of titanium and Type 316 stainless steel could be coupled together to determine the effect of the area fraction on cathodic polarization. The reaction which occurs on both surfaces is reduction of ferric ions to produce ferrous ions.

Procedure

The procedure and equipment were essentially the same as that reported previously[1] except that the cell consisted of a seven-liter cylindrical battery jar covered by a Plexiglas gasketed plate through which the electrodes were immersed in the solution. Platinized platinum was used as a reference electrode and as auxiliary anodes during polarization. The solution, which was nitrogen-saturated at all times, was prepared by adding 100 grams of $FeCl_3 \cdot 6H_2O$ and 30 grams of sodium nitrate to 1000 grams of water. Sufficient ferrous chloride was added to bring the ferrous-ferric redox potential to + 0.789 volt on the standard hydrogen scale.

Six electrodes (three titanium and three stainless steel) of various sizes were introduced into the solution, and the cell was operated for a period of two months during which the reported polarization measurements were obtained. The temperature during this interval varied from a maximum of 26.4 C to a minimum of 24.5 C. The ferrous-ferric redox potential of the solution varied from + 0.788 to + 0.790 volt.

Results

For purposes of simplification, each electrode is designated by its composition and approximate area. Thus, 316(0.9) refers to the stainless steel electrode with an area of 0.88 sq cm and Ti(5) to the titanium electrode with an area of 4.46 sq cm (see Table 1).

Figure 1 shows the cathodic polarization curves obtained for the six individual electrodes plotted on a current basis. The exchange current and Tafel beta values for these data are presented in Table I. When plotted on a current density basis, the three stainless steel samples fall approximately on one line as do the 5 sq cm and 50 sq cm titanium

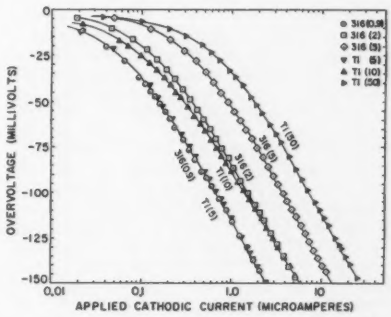

Figure 1—Cathodic polarization of individual electrodes plotted on a current basis.

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About the Author

MILTON STERN is a Research Metallurgist at the Metals Research Laboratories, Electro Metallurgical Company, Union Carbide Corporation, Niagara Falls, New York. He received a BS in chemical engineering at Northwestern University and an SM and ScD from Massachusetts Institute of Technology in physical metallurgy. He was Weirton Post-doctoral Fellow at the corrosion laboratory of MIT for two years prior to joining the Metals Research Laboratories. Dr. Stern was presented the Young Authors Award of the Electrochemical Society in 1955 and is Corrosion Division Editor of this Society. He is also Secretary-Treasurer of the Niagara Frontier Section of NACE.

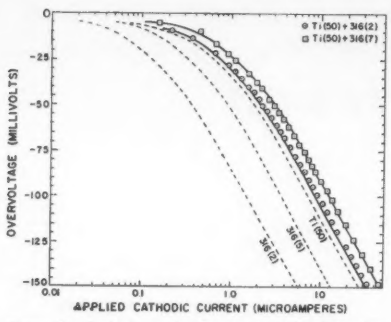

Figure 2—Cathodic polarization of bi-electrodes formed by coupling a 50 sq. cm. titanium sample to stainless steel.

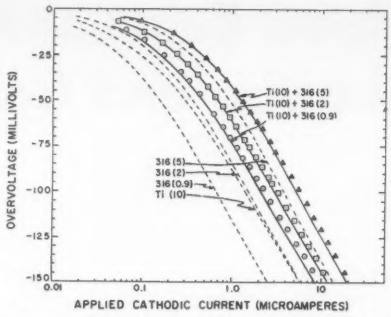

Figure 3—Cathodic polarization of bi-electrodes formed by coupling a 10 sq. cm. titanium sample to stainless steel.

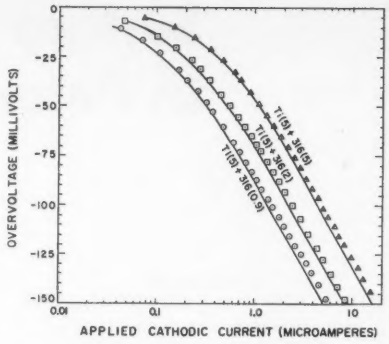

Figure 4—Cathodic polarization of bi-electrodes formed by coupling a 5 sq. cm. titanium sample to stainless steel.

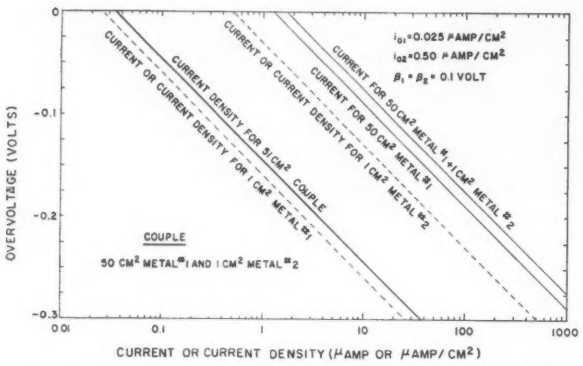
i_{01}=0.025 μAMP/CM²
i_{02}=0.50 μAMP/CM²
$\beta_1 = \beta_2$ = 0.1 VOLT
COUPLE
50 CM² METAL #1 AND 1 CM² METAL #2
OVERVOLTAGE (VOLTS)
CURRENT OR CURRENT DENSITY (μAMP OR μAMP/CM²)

Figure 5—Example of the influence of contamination of a high overvoltage surface with a small region of low overvoltage.

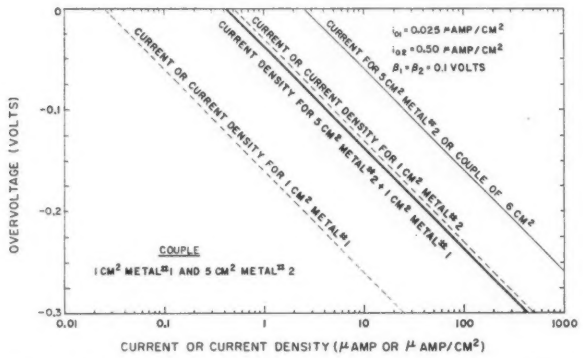
i_{01} = 0.025 μAMP/CM²
i_{02} = 0.50 μAMP/CM²
$\beta_1 = \beta_2$ = 0.1 VOLTS
COUPLE
1 CM² METAL #1 AND 5 CM² METAL #2
OVERVOLTAGE (VOLTS)
CURRENT OR CURRENT DENSITY (μAMP OR μAMP/CM²)

Figure 6—Example of the influence of contamination of a low overvoltage surface with a region of high overvoltage.

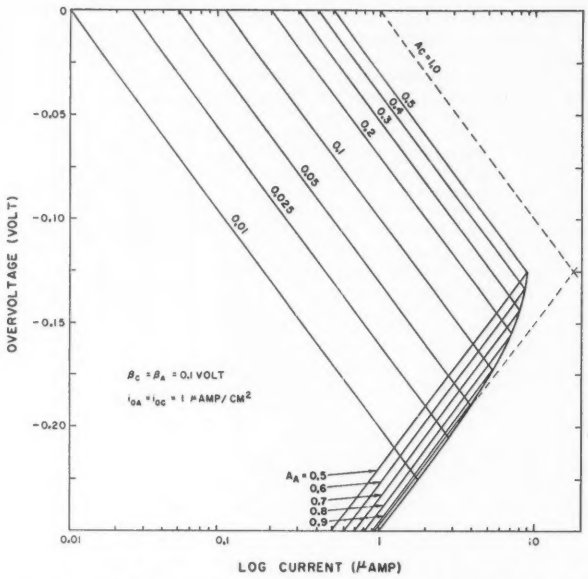

Figure 7—The effect of changes in anode and cathode area fraction of a corroding surface on the position of the local polarization curves.

samples. The 10 sq cm titanium electrode exhibits a lower exchange current density and Tafel slope, but this was not considered serious for the present purpose.

Table 1 shows the exact areas and exchange current densities for the various electrodes along with the potential of each electrode without current application. In two separate runs, the Ti(50) electrode was coupled to the 316(2) electrode and to a couple of 316(2) and 316(5) and the polarization curves obtained. Figure 2 shows the results obtained. The three dashed lines are reproduced from Figure 1 and represent the polarization curves of the individual electrodes. The heavier solid line is the sum of the pertinent individual curves and is not necessarily intended to lie along the experimental points. It can be seen, however, that there is good agreement between the algebraic sum of the individual currents and experimental points for the couples.

Similar experiments were conducted by coupling the Ti(5) and Ti(10) samples to the 316 electrodes. The results are shown in Figures 3 and 4. The individual curves are not included in Figure 4 since this tends to crowd the plot. It should be emphasized again that the solid lines represent the algebraic sum of the individual curves and are not intentionally drawn through the experimental points. In general, the agreement is quite good and deviations probably can be attributed to changes in the characteristics of the individual surfaces during the two-month duration of the experiment.

Discussion

The above results show that a measured polarization curve on a surface with regions of different overvoltage behavior is the sum of the individual polarization curves when plotted on a current basis. It is very important to note that it is incorrect to sum the data on a current density basis. Thus, while it is true that

$$I_T = I_1 + I_2 \qquad (1)$$

the sum of the individual current densities does not equal the total couple current density.

$$\frac{I_T}{A_1 + A_2} \neq \frac{I_1}{A_1} + \frac{I_2}{A_2} \qquad (2)$$

where I_T is the total current and I_1 and I_2 are the individual currents. In most cases the individual area relationships of an electrode are unknown. Therefore, even though the surface contains regions with different overvoltage parameters, it is only possible to divide the total current by the total area. It is important to realize, however, that

$$\frac{I_T}{A_1 + A_2} = \frac{I_1 + I_2}{A_1 + A_2} \qquad (3)$$

which can be rearranged to give

$$i_T = f_1 i_1 + f_2 i_2 \qquad (4)$$

where the lower case i represents current density and f_1 and f_2 are the fractions of the surface occupied by regions 1 and 2, respectively.

Equation 4 has practical significance which can best be described in the following manner. Consider a surface with one region of quite high overvoltage* (region 1) and another of low overvoltage (region 2). At the same potential, i_1 will be quite small in comparison to i_2, so that the measured current density of the entire surface is essentially proportional to $f_2 i_2$. This means that measurements of Tafel parameters on high overvoltage surfaces will be markedly influenced by small amounts of low overvoltage contamination. On the other hand, low overvoltage surfaces are not significantly affected by small amounts of contamination with high overvoltage impurities. This can be illustrated graphically by considering a surface with regions having exchange current densities of 0.025 (region 1) and 0.50 microampere/sq cm (region 2). The Tafel beta values may be considered equal at 0.1 volt.

A situation where the total surface area is 51 sq cm with 1 sq cm consisting of region 2 is illustrated in Figure 5. The dashed lines represent the true potential-current density relationship for 1 sq cm of regions 1 and 2. The light weight solid lines represent the potential-current relationships for 50 sq cm of region 1 and the composite surface of 51 sq cm. The heavy line is the resulting potential-current density curve which would be obtained experimentally if one were actually working with surface 1 which was covered with approximately 2 percent of surface 2. The measured exchange current density would be 0.034 microampere/sq cm as opposed to the real value of 0.025—an increase of approximately 36 percent.

To illustrate the smaller influence of contaminating a low overvoltage surface with high overvoltage impurities, consider a total area of 6 sq cm consisting of 1 sq cm of region 1 and 5 sq cm of region 2. Figure 6 shows the pertinent individual polarization curves in a similar manner to that illustrated in the previous figure. In this case at constant potential the total current on the 6 sq cm surface is essentially the same as that on the 5 sq cm area of region 2 since the current contribution from region 1 is negligible. Therefore, the measured exchange current density would be reduced by the fraction of the surface occupied by region 2—a reduction from 0.50 microampere/sq cm to 0.42 microampere/sq cm.

From the two examples presented above, it can be seen that covering a high overvoltage surface with approximately 2 percent of a low overvoltage region increases the measured exchange current by 36 percent, whereas covering a low overvoltage surface with as much as 17 percent of a high overvoltage region produces a reduction of measured exchange current density of 16 percent.

Some of the principles illustrated above have been shown qualitatively by Machu and Fouad[2] who studied hydrogen overvoltage on bimetallic electrodes. Unfortunately, their experimental procedure was not ideal, since the individual metals which were used contained mixed electrode regions in many cases. Hansen and Wetmore[3] clearly recognized the importance of impurities in metals on resulting overvoltage measurements during their work on hydrogen overvoltage on aluminum. Their results were interpreted by considering that the overvoltage on aluminum was much greater than the overvoltage on the minute exposed areas of impurities on the surface. Thus, these small regions carried most of the current so that their measurements represented overvoltage behavior on a small fraction of the total area. They also claimed that the corrosion potential of their alloys was simply determined by the area of impurities exposed and the overvoltage on these areas at the corrosion current. There appear to be many systems where this kind of analysis could prove helpful in interpretation of observations.

Area Relationships on Corroding Electrodes

In addition to the factors described above which may influence overvoltage measurements on surfaces where only one oxidation-reduction reaction proceeds, other factors concerning corroding electrodes require further consideration. These are systems where two or more oxidation-reduction reactions proceed at the same surface. In particular, one may subdivide the surface into regions where the predominant reaction is reduction (cathode areas) and regions where the predominant reaction is oxidation (anode areas).

Polarization diagrams which introduce the concept of exchange current[4,5] are particularly useful in graphically illustrating how anode and cathode area changes affect the corrosion rate and the corrosion potential. This is true because the exchange current is a function of area even though the exchange current density is a constant for any particular electrode process. Thus, changes in cathode or anode area move the position of the local polarization curves to the left or the right, changing their intersection. For example, consider a 1 sq cm corroding system with a cathodic activation polarization curve which exhibits an exchange current density of 1 microampere/sq cm and a Tafel slope of 0.1 volt along with an anodic activation polarization curve with the same Tafel parameters whose reversible potential is 0.25 volt more active than the reversible potential of the cathodic reaction.

Figure 7 shows these polarization curves on a unit area basis as dashed lines. The potential scale uses the equilibrium value of the cathodic process as reference. If the 1 sq cm surface is divided into equal portions of anode and cathode ($A_1 = A_2 = 0.5$), then the exchange current for each 0.5 sq cm area is 0.5 microampere. The local polarization curves for this condition are also shown on Figure 7 where it is found that their intersection (the corrosion potential and corrosion current) occurs at —0.125 volt and 9.1 microamperes. The locus of all such intersections for various anode and cathode area fractions is drawn as a solid curve in this figure. It is interesting to note that all corrosion potentials between the equilibrium potentials of the two redox systems are obtained. In addition, the maximum corrosion current exists when the anode and cathode areas are equal.

The Effect of Cathode Area Fraction on Corrosion Potential

It is possible to derive the relationship between corrosion potential and area fraction for a system like that illustrated in Figure 7. Considering only activation polarization, the Tafel overvoltage equations for the separate anode and cathode processes may be written as:

$$\eta_c = -\beta_c \log \frac{i_c}{i_{oc}} \qquad (5)$$

$$\eta_a = -E_a + \beta_a \log \frac{i_a}{i_{oa}} \qquad (6)$$

where η_a and η_c are the potentials of anode and cathode areas, respectively; β_c and β_a are the Tafel slopes for anode and cathode areas; i_a and i_c are the anodic and cathodic current densities, respectively; and i_{oa} and i_{oc} are the anodic and cathodic exchange current densities.

The exchange current densities and beta values for the anodic and cathodic reactions are constant and are properties of the individual electrode processes. They are not dependent upon the total area of either region. The exchange current, however, is influenced by area. Considering 1 sq cm total area, Equations 5 and 6 may be rewritten

$$\eta_c = -\beta_c \log I_c + \beta_c \log A_c i_{oc} \qquad (7)$$

$$\eta_a = -E_a + \beta_a \log I_a - \beta_a \log A_a i_{oa} \qquad (8)$$

* In this discussion, a region of high overvoltage is considered one with a low exchange current density which polarizes markedly with small values of current.

TABLE 1—Electrochemical Data for Stainless Steel and Titanium Electrodes

SAMPLE	Total Area (sq cm)	Exchange Current (μamp)	Exchange Current Density (μamp/sq cm)	β (Volt)	*η_{corr} (Millivolt)
316 (0.9)	0.88	0.048	0.0545	—0.087	—0.5
316 (2)	1.96	0.106	0.0541	—0.087	—0.4
316 (5)	4.94	0.28	0.0567	—0.088	—0.5
Ti (5)	4.46	0.048	0.0108	—0.087	—3.3
Ti (10)	10.05	0.082	0.0082	—0.081	—2.6
Ti (50)	49.47	0.53	0.0107	—0.088	—3.2
Ti (5) +316 (1)	5.34	0.094	0.0176	—0.088	—1.0
Ti (5) +316 (2)	6.42	0.170	0.0265	—0.087	—0.8
Ti (5) +316 (5)	9.40	0.33	0.0351	—0.086	—0.5
Ti (10) +316 (1)	10.93	0.13	0.0119	—0.081	—1.1
Ti (10) +316 (2)	12.01	0.19	0.0158	—0.082	—1.1
Ti (10) +316 (5)	14.99	0.38	0.0254	—0.086	—0.8
Ti (50) +316 (2)	51.43	0.65	0.0126	—0.087	—2.1
Ti (50) +316 (7)	56.37	0.86	0.0171	—0.086	—1.6

* The difference in potential between the sample and a platinum electrode in the same solution

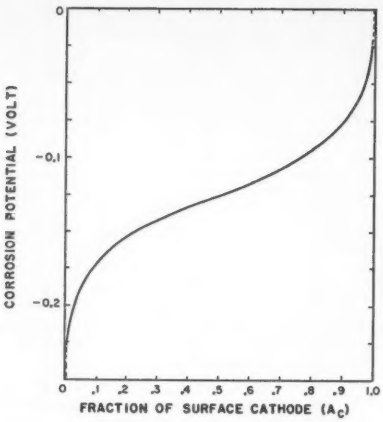

Figure 8—The effect of cathode area fraction on corrosion potential.

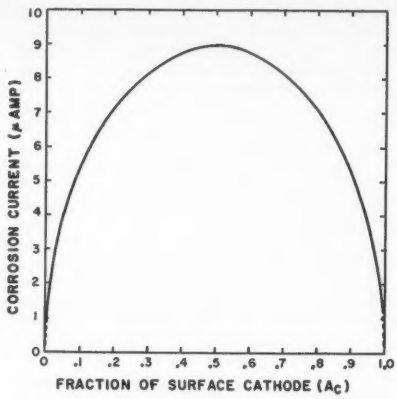

Figure 9—The effect of cathode area fraction on corrosion current.

where I_a and I_c are the anodic and cathodic currents, respectively, and A_a and A_c are the fractions of a 1 sq cm surface represented by anode and cathode.

At the corrosion potential where anode and cathode areas are polarized to the same potential, $\eta_c = \eta_a = \eta_{corr}$ and $I_c = I_a = I_{corr}$. Substituting these values in Equations 7 and 8 produces

$$\log I_{corr} = -\frac{\eta_{corr}}{\beta_c} + \log A_c i_{oc} \quad (9)$$

$$\log I_{corr} = \frac{\eta_{corr}}{\beta_a} + \frac{E_a}{\beta_a} + \log A_a i_{oa} \quad (10)$$

Equating the rights side of Equations 9 and 10 and rearranging produce

$$\eta_{corr} = -\frac{E_a\beta_c}{\beta_c+\beta_a} - \frac{\beta_c\beta_a}{\beta_c+\beta_a}\log A_a i_{oa} + \frac{\beta_c\beta_a}{\beta_c+\beta_a}\log A_c i_{oc} \quad (11)$$

which shows how the corrosion potential varies with the fraction of area which is anode or cathode. Differentiating the corrosion potential in respect to A_c with E_a, β_a, β_c, i_{oc}, and i_{oa} constant yields

$$\frac{d\eta_{corr}}{dA_c} = \frac{1}{2.3}\left(\frac{\beta_c\beta_a}{\beta_c+\beta_a}\right)\left(\frac{A_a+A_c}{A_aA_c}\right) \quad (12)$$

This gives the change in corrosion potential with fraction of cathode area and shows that the corrosion potential is most sensitive to area relationships when either A_a or A_c is small.

The influence of area relationships on corrosion potential can perhaps be more clearly illustrated by assigning values to the constants in Equation 11 and plotting corrosion potential as a function of A_c. Figure 8 is such a plot using the same values for the constants as used in Figure 7. It is interesting to note that an inflection point occurs at $A_c = A_a = 0.5$. In this region, the corrosion potential is least influenced by area fraction.

The Effect of Cathode Area Fraction on Corrosion Current

The same kind of analysis as used above can be applied here to determine how the corrosion current varies with change in A_c or A_a. Eliminating η_{corr} from Equation 9 and 10 and rearranging produce the following relation

$$\log I_{corr} = \frac{E_a}{\beta_a+\beta_c} + \frac{\beta_c}{\beta_a+\beta_c}\log A_c i_{oc} + \frac{\beta_a}{\beta_a+\beta_c}\log A_a i_{oa} \quad (13)$$

or

$$\frac{d\log I_{corr}}{dA_c} = \frac{\beta_c A_a - \beta_a A_c}{(\beta_a+\beta_c)A_aA_c} \quad (14)$$

Thus, as either A_a or A_c approaches zero, the corrosion current is markedly influenced by changes in area fraction. Also the corrosion current is a maximum when the surface is half anode and half cathode. Figure 9 shows the corrosion current as a function of A_c using the same values for the constants used previously in Figures 7 and 8.

It is important to note that Equations 11 to 14 do not apply in the limit where A_c or $A_a = 1$ because under these conditions the system no longer may be considered a corroding electrode. If the surface is all cathode, then η is zero and the original cathodic reaction is at equilibrium on the electrode surface. If the surface is all anode, then $\eta = E_a$ and the surface is a reversible metal-metal ion electrode.

The discrepancy in these equations when the corroding electrode approaches the reversible potential of either redox system occurs because in these potential regions the reverse reactions of the redox systems become important. This has been discussed adequately by Stern and Geary[5] and will not be described here further. The corrections for the reverse reactions could be introduced into the above equations, but this added complexity appears unnecessary for the present purposes.

Discussion

Anode and cathode area changes have long been recognized as important variables in corroding systems. Unfortunately, no good experimental method has yet been described which permits determination of the fraction of a corroding surface which functions as anode or cathode at any one time. It is possible that indirect methods will have to be used for measurements of this property. For example, Equations 11 and 13 above could be used to determine A_c or A_a if the Tafel parameters of the separate oxidation and reduction reactions were determined under conditions where the entire surface functioned as anode or cathode. In many cases, this is difficult or impossible to do experimentally.

The analysis presented here illustrates several important concepts which are worth listing.

1. A polarization curve on a surface with regions exhibiting different overvoltage parameters for the same reaction is the sum of the individual polarization curves when plotted on a current basis. Thus, $I_T = I_1 + I_2$ or $i_T = f_1 i_1 + f_2 i_2$.
2. Polarization measurements on high overvoltage surfaces are markedly influenced by small amounts of contamination from low overvoltage impurities. On the other hand, low overvoltage surfaces are not significantly affected by small amounts of high overvoltage contamination.
3. Polarization diagrams which introduce the concept of exchange current can be used to show how anode and cathode area changes affect corrosion rate and corrosion potential.
4. Various anode and cathode area fractions can produce corrosion potentials which range between the equilibrium potentials of the major anodic and cathodic processes.
5. The corrosion potential and the corrosion current are most sensitive to area changes when the surface is predominantly anode or cathode.
6. The maximum corrosion current occurs when a corroding surface is equally divided into anodic and cathodic regions.

While only activation polarization has been considered here, the same kind of analysis could be applied to polarization diagrams which include concentration polarization. It is believed that introduction of this additional complexity, even though closer to behavior in some real systems, is unnecessary to illustrate the basic principles which have been described.

Acknowledgment

The author would like to acknowledge the skillful assistance of E. A. Tomes who conducted the electrochemical measurements.

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Any discussions of this article not published above will appear in the December, 1958 issue

Cathodic Protection of Radiant Heating Pipes*

By L. C. WASSON

Abstract

In trying to apply cathodic protection to radiant heating pipes, it was not possible to provide protection from an external ground bed so distributed anodes were installed through a concrete floor. Because some 500 anode clusters were installed in a space 300 x 1200 feet some unusual techniques of application had to be developed to make the installation feasible. These techniques, along with the reasoning that led to their use are described. Also mentioned are some of the problems encountered in trying to determine if and when complete protection of the system was obtained.

Cost data pertaining both to the installation and the operation of this cathodic protection system are reported.

5.2.3

Introduction

WHEN THE Kankakee plant of the A. O. Smith Corporation was taken over from the building contractors in 1947, it was hailed as one of the largest installations of radiant heating up to that time. It covered a floor space 300 feet wide by 1200 feet long with radiant heating piping underneath the whole area. Unfortunately, the architects and builders who designed and constructed the building were not familiar with some of the pitfalls that can be met with radiant heating systems, and thus some of the pipe was allowed to lay on the ground while concrete was poured around it.

Figure 1 shows the resulting corrosion of the bottom of the pipe, with the edge of the corrosion pattern ending at the line where the concrete began to encase the pipe. Two leaks were recorded through 1950, but in 1951 a total of 22 leaks were encountered.

When the management of the plant began to notice the high rate of increase in leaks, personnel from the Research Division were called in to help them discover the cause, and to offer methods for mitigation of the corrosion. Cathodic protection was the suggested remedy, but the biggest question was how to apply the current. Because of installation costs, the first method tried was the installation of a number of carbon anodes outside the building. When the writer became associated with the problem, after this installation was made, a study was made of the effectiveness of the external anode system in introducing current onto the exposed piping. This was done by making holes in the floor of the building and contacting the earth beneath with calomel cells. The holes formed a line perpendicular to the line of anodes outside the building, and were about 50 feet apart. These cells were connected to a Beckman Type G potentiometer. The potential difference was determined with the anode bed energized. Then the current was turned off, and the effect on the potential difference noted. The difference, while detectable on the galvanometer of the meter, was so small that it was impossible to measure accurately with the meter used. From this it was concluded that the current was not getting to the pipes in sufficient quantities to accomplish any appreciable corrosion prevention. (Later information brought out the fact that the foundation around the outside of the building was extended down to the bed rock, which was only a matter of four to ten feet.)

The next type of cathodic protection installation considered was that of installing anodes through the floor of the building, distributed throughout the building. The big question was that of how far the current could be expected to "throw" when the anodes were installed underneath the floor, with their maximum distance only about 10 feet from the piping they were to protect. A test installation was made, as indicated by Figure 2 in which the anodes were installed at the foot of each building column for a section three columns wide by five columns long, with the dimensions given in Figure 2. By the time the studies on this installation had been completed, another 20 leaks had occurred, and the maintenance engineers were beginning to think that the system was so far corroded away that there was no point in trying to save it. The alternative was to install a mechanical overhead convection system at a minimum cost of approximately $100,000.

The information obtained from this preliminary test indiciated that satisfactory current distribution could be obtained if an anode installation were made at each building column, with some reason to believe that an installation at every other column might work.

About the Author

L. C. WASSON is Director of the Electrochemical Laboratory in the Research and Development Division of the A. O. Smith Corporation, Milwaukee, Wisconsin. He received a BSEE degree from University of Arkansas in 1933. Since that time he has been active in research and development work in a number of fields, including hydraulic, mechanical and electrical engineering. In 1951 he organized the Electrochemical Laboratory to work with cathodic protection and associated phenomena.

Installation of System

Because of the uncertainty on the part of maintenance people as to whether the system was worth saving, it was necessary to develop an installation technique that would hold the installation costs to as low a figure as possible (else the risk of making the expenditure would not be considered to be justified). But at the same time, it was imperative that the system as installed should work satisfactorily since one installation already has failed.

With these two conflicting conditions as the criteria, it was decided to install the anodes at the base of each column, with the installation of each anode to be as described below.

The installation of the anodes was accomplished by breaking a hole in the concrete near the base of a column. When the hole had been opened up, an iron rod 1 5/16 inches in diameter was driven into the ground with an air hammer at an angle of about 45 degrees. The rod was driven until it hit the rock below the floor, or until a total of 10 feet had been driven.

A second rod was driven into the ground at about 45 degrees, but aimed approximately 180 degrees away from the first rod, where possible. When the rods were driven to a point where the top end was below the surface of the concrete, lead wires were brazed to them, and copper tubing was threaded over the lead wires. This copper sheathed wire was laid in a groove cut in the concrete from the anode to a point inside the flanges of the column. (Figure 3 shows the copper sheathed wire coming out of the floor within the protection of the column flanges and the anode lead wire coming down from the top of the column.)

The top of the anode, the junction of the lead wire with the anode, and the bottom of the copper tubing were covered by pouring hot coal tar into the hole in the concrete. When that had hardened, the hole and groove was brought back to the original level by pouring cement into them. This area

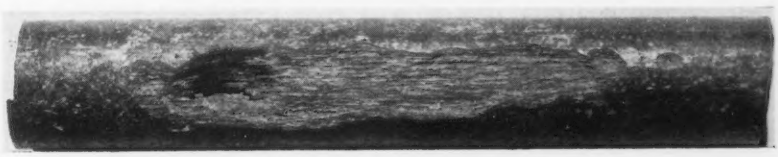

Figure 1—Section of radiant heating pipe taken from the floor of the Kankakee plant. Cathodic protection was applied later to stop this type of corrosion.

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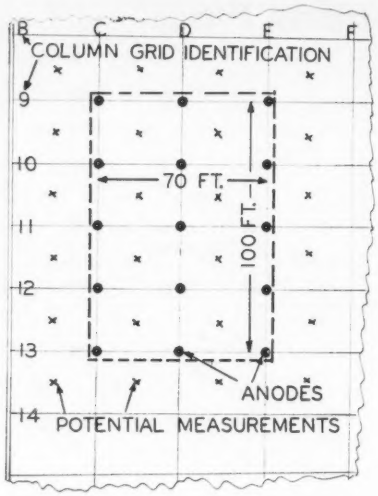

Figure 2—Preliminary test layout.

Figure 3—Anode leads encased in copper tubing and coming out of the floor between the flanges of the building column.

shows up in Figure 3 as a light patch extending from the right of the picture into the space between the column flanges. A schematic arrangement of the anode portion of the installation is shown in Figure 4.

The distribution of current to the approximately 500 anode clusters distributed over the space of 300 feet by 1200 feet created a problem because a total of 250 amperes was contemplated as the current to be delivered to the anodes. The final solution was to buy a number of relatively low capacity rectifiers, rated at 20 amperes output, but loaded only to 10 amperes (feeding 20 anode clusters) because of summer temperatures encountered at the ceiling where the rectifiers are installed. The particular rectifiers used had the possibility of obtaining either zero to eight volts, or zero to sixteen volts by a simple switch arrangement. The output voltage was adjustable within each range over a number of taps, so that it was possible to obtain a wide selection of applied voltages.

In order to maintain a uniform current distribution to the anodes connected to a single rectifier, it was necessary to compensate for the resistance of the lead wire from the power source to the

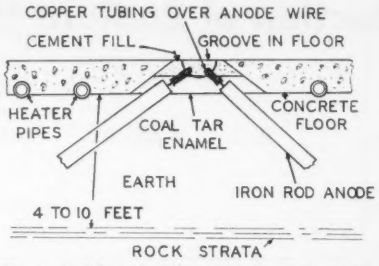

Figure 4—Schematic diagram of anode cluster installation.

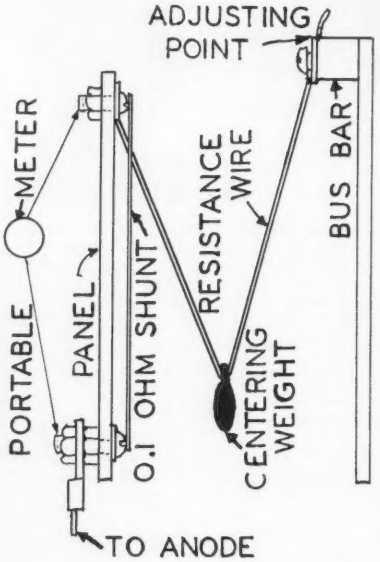

Figure 5—Schematic diagram of resistance adjustment on distribution panel.

anode. Figure 5 shows a schematic arrangement by which this was accomplished simply and effectively. A bus bar was connected to the rectifier positive connection. From that bus bar, through a screw and washer arrangement, a length of resistance wire was connected. The other end of the resistance wire was connected through a permanent connection to the top of a 0.1 ohm shunt. The shunt was mounted on a masonite panel, with terminals extending through the board, so that a 50 MV meter could be attached by probes to the ends of the shunt. The bottom end of the shunt was connected to a wire leading to one of the anode clusters at the base of a column. In order to keep the resistance wire from curling up and shorting out neighboring resistance wires, a fishing sinker was installed on each resistance wire, which kept all wires hanging downward and out of the way of each of its neighbors.

Figure 6 shows a view of a rectifier installation, and a front view of a distribution panel. Figure 7 is a view looking up at the bottom of the installation, showing how the weights were used to hold the wires in place.

When it was desired to change the resistance in a particular anode circuit, the screw and washer connection was loosened at the bus bar, and the resistance wire was changed in length, either lengthened or shortened as the requirements dictated. The amount of wire left

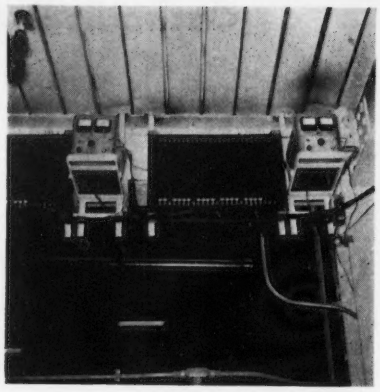

Figure 6—View of rectifier and distribution panel showing front of panel.

extending beyond the screw connection was simply left to its own devices, because any contacting of the wires at this point would not make any difference in the circuit characteristics, since the connection was to a common bus. With this arrangement, it was possible to utilize 14 gage hook-up wire between the anode and the rectifier, thus cutting down on the cost of the wire that would otherwise have been required if an attempt had been made to minimize the voltage drop in the lead wire.

With installation costs cut to the apparent limit, permission was obtained to make an installation on a portion of the building to observe the results. In July of 1953, power was turned on in the first portion, covering about ⅔ of the total area. Because of factors explained under "Criteria of Protection," the use of potential measurements was not a good method of determining quickly whether protection was being obtained. Therefore, test stations were installed at a number of spots in the area. In each of these stations, a hole was cut in the floor, and two steel rods ¼ inch in diameter were driven into the ground. One rod was attached to the pipes receiving protective current and the other one was left unattached. At the end of 3 months time—before the leak frequency began to show a significant change—these rods were examined. They showed in a very convincing manner how the current was protecting the steel. With this visual evidence available, it was not difficult to get a decision to install protection on the rest of the structure. By July of 1954, the current was turned on in the last portion of the building.

Results

From some preliminary calculations, plus some educated guesses as to the manner in which the current would distribute itself over the structure, it was decided that a current of 500 milliamps should be distributed from each cluster of two iron anode rods attached to each anode lead wire. The curves in Figure 8 show how well this current was performed to protect the system. The total number of leaks per year in the whole plant has been plotted against the year in which they appeared. This shows that after cathodic protection was applied, the rate dropped off rapidly.

The last leak to appear on the system was in April of 1955. With such complete control over the number of leaks, steps have been taken to reduce the

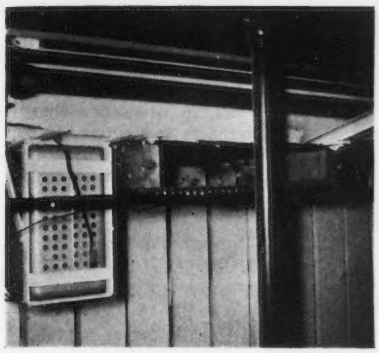

Figure 7—Bottom view of rectifier and distribution panel, showing weights used to hold resistance wires in position.

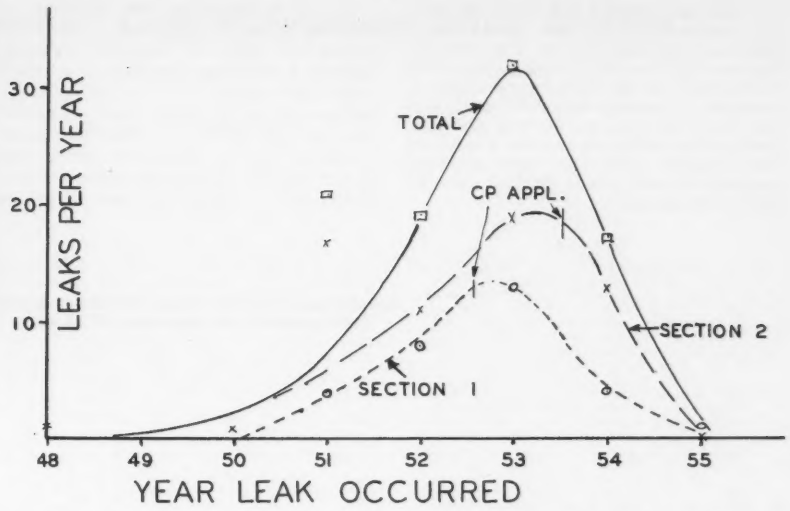

Figure 8—Leak rate curve. Total leaks per year are shown as are the leaks per year in the two separate sections involved in the total installation.

amount of current flowing from each anode. At the present time, the current has been reduced to about 375 milliamperes average through each anode cluster. Because of its effect on prolonging the life of the anodes, the current will be reduced gradually until a few leaks begin to show up, since the cost of repairing a few leaks will be less than that of replacing the anode system a year or two sooner than would otherwise be necessary.

The use of iron anodes driven into the ground without any backfill has worked out very well from the angle of the voltage necessary to deliver the current desired. The average voltage required to deliver 500 milliamps to the anode systems was in the order of 7 to 8 volts, with the values ranging from a low of about 5 volts to a high of about 11 volts.

After 32 months of operation, two anode clusters, composed of four anode rods, were taken up and examined. After cleaning, they showed an average weight loss of 23 percent of the total, or a figure of approximately 25 pounds per anode cluster. An estimated average of the current through the anodes for that time is 450 milliamps. Over a period of 32 months, that would amount to 10,500 ampere hours, giving a result of 420 ampere hours per pound of iron used. The electrochemical equivalent of iron reduced to the ferrous state is 435 ampere hours per pound.

One factor that was noted in the examination of these rods was that the upper quarter of the rod (about 2½ feet) was corroded very little. This means that 25 percent of the iron in this installation will not be easily available for providing protection. Since this has been observed, plans for replacement of the present anode system (when its full life has been attained) will take this fact into consideration.

Costs

The estimated cost for installing the anode portion of this system was about $12,000. The estimated life of the system, based on the examination of two anode clusters at the end of 32 months, would be nine years. The current from the anodes has been cut down to under 400 milliamps now, and it might well be cut to 350 or less before any leakage begins to show up. If 450 milliamps will give nine years, then 350 milliamps should give about 11½ years. When it is considered that in the next installation the 25 percent of the iron that is not now active will be redistributed to be used more effectively, a life of 12 years might well be assumed for the anode system at a cost of $12,000. This would make a cost of $1,000 per year for anode installation.

Power costs would run about $600 per year, based on power at 2 cents per kw-hr, current at 350 milliamps in each of 500 anode clusters, and voltage at 8 volts average. Also, it is based on power being delivered to the anode at an efficiency of 50 percent (rectifier efficiency is around 80 percent).

Maintenance of the system requires a "walk around" look at the rectifiers once a week to see that power is on all of them—a matter of about ½ hour. About every three months, a detailed check of the currents to each anode is made, which requires about 20 hours, including time required for any adjustment made to maintain currents at a desired level. This would total 106 hours per year, or about $300 per year. Engineering costs to follow the progress of the system do not cost over $200 per year.

When the total costs are added together, a figure of about $2,100 per year would be the operating cost of the system. It was estimated that, when all the costs of the successful installation plus the early investigations and studies were considered, a saving of $70,000 was effected by not having to install a mechanical convection system. If one had to pay 3 percent interest on the money that would have been used to install a mechanical system, the saving in interest by the installation of cathodic protection would pay for the full operating costs of the system.

Criteria of Protection

When the first preliminary work was undertaken to set up a cathodic protection system, attempts were made to determine by means of potential measurements when protection was obtained. However, the variability of results made the use of this criterion unworkable under the conditions of installation. For example, it was not uncommon to measure a potential (at the top surface of the concrete floor) of minus 0.44 volt to a calomel electrode at one spot, and at another spot six inches away measure a potential of minus 0.95 volt. These potentials would repeat quite accurately, when moving the cell from one location to the other at the time of making the observations, so they were not due to variations in testing techniques. Because of the large variations at short spacing, and because it was not feasible to mark spots for exact relocation of cells when making readings on a later survey, it was decided that for this system the use of potentials as a criterion for protection could not be used. Consequently, it has been necessary to utilize the leak record at the criterion. This necessarily means slow work in adjusting the currents to a point where they will not be over-protecting the system, but it has been felt that this method is cheaper than the extensive testing and statistical correlation that would be necessary to work with potential values under the existing conditions.

Acknowledgment

In conclusion, acknowledgment is made of the contribution to the preliminary testing and planning stages of this work by Dr. H. F. Haase, Corrosion Consultant, and thanks are extended for his cooperation.

DISCUSSION

Question by Harold C. Boone, Peoples Gas Light and Coke Company, Chicago, Illinois:

What was the average current density (milliamperes per square foot of exposed bare metal) found necessary for this type of cathodic protection.

Reply by L. C. Wasson:

It is not possible for us to arrive at anything better than a guess as to the current density. This is because we do not know how much of the individual pipes are exposed, and we do not know how much other area is exposed, such

as columns extended below the concrete to column footings, and other miscellaneous steel exposed to the cathodic current. We are continuing to cut down the current as our leak record seems to warrant it (present value 375 milliamps per anode group), so we will not even know what minimum current is required for complete protection until we have reached a point where the leak rate begins to go up again.

As an indication of our thinking in arriving at a starting figure, we estimated one fifth of the pipe exposed, figured a minimum current of 3 milliamps per square foot at the greatest distance from the anode, and estimated that the current density near the anode would go up to about five times that at the greatest distance from the anodes. When we averaged this out to arrive at a total current from each anode cluster (the anodes driven at each column) we had a figure of something like 300 milliamps. Then we increased the current at each cluster to 500 milliamps simply as an assurance that we would get complete protection, because so much was dependent on our being able to provide the protection we had claimed we could get.

Any discussions of this article not published above will appear in the December, 1958 issue

TECHNICAL PAPERS ON CORROSION WELCOMED

Authors of technical papers on corrosion are invited to submit them for review without invitation to the Editor of Corrosion. Write for "Guide for the Preparation and Presentation of Papers" sent free on request to prospective authors.

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Service Performance of Cast Magnesium Alloy Anodes*

By G. L. CHRISTIE*

Abstract

During the course of development of cathodic protection systems suitable for the protection of active ships, a number of different designs of anodes have been tried and considerable differences in their behavior have been noted in ship trials. The designs tested have included sand cast cylindrical anodes with cast-in steel conductor rods, which corroded in a very uniform pattern, and chill cast rectangular anodes with cast-in retaining straps, which corroded preferentially at the cast-instraps. The magnesium alloy used in all cases was AZ-63. Chemical analysis of the metal indicates that the only major difference in the two anodes is inverse segregation of the major alloying constituents in the chill cast anodes. The inverse segregation found produces an anode with the most actively anodic metal on the inside of the casting. Any puncture of the anode surface (in the vicinity of a cast-in strap, for example) will lead to preferential attack at the point of puncture. Laboratory tests of the anode metal from chill cast ships' anodes and unsegregated anodes, indicates that there is sufficient difference between the outside metal and inside metal to account for the corrosion pattern observed in ship trials of chill cast anodes. 5.2.2

Introduction

PROTECTION SYSTEMS have been tried on both inactive and active ships in the eleven years that have elapsed since work on the cathodic protection of ships was begun. With alterations in the systems, a number of different designs for anodes were used, and their behavior in service noted. These alterations in design and in the numbers of anodes ordered, sometimes dictated an alteration in casting methods used in the foundry.

It has been observed that corrosion patterns vary considerably from one anode to another. Since the efficiency of use of magnesium frequently is related to the corrosion pattern of the anode, this investigation was undertaken to determine, if possible, the reason for the inefficient corrosion pattern observed in ship trials with some anodes.

Service Performance of Ship Anodes

The original pattern (Mark I) anode, made especially for protection of inactive ships, was a cylindrical sand casting. This anode, six inches in diameter and 48 inches long, carried a centrally located one-quarter inch steel pipe core and a steel crossbar used for attachment of the rope for suspension. In service it corrodes very uniformly, with little or no tunneling from local action at the bare steel core or crossbar (Figure 1). This pattern is still in use.

The first installation of a magnesium anode system on an active ship, larger than a small tug, was made in June, 1949. The behavior of the anodes has been described elsewhere.[1] The cause of the unsatisfactory behavior of these anodes was copper contamination from the cast-in conductor bars; suggestions for preventing this difficulty have been given elsewhere.[2] A modified anode, cast with a chill plate next to the copper conductor, was satisfactory insofar as contamination of the anode metal with copper was concerned.

The next modification was made to reduce the expense of casting by using a permanent steel mould and to provide a more convenient and flexible method of attachment and renewal. The design is indicated in Figure 2. The new anodes were 10 inches wide, 3 inches thick and 60 inches long. Two 5/16 inch diameter steel bars were included to allow the anode to be split for installation on narrow bilge keels and to provide a secondary precaution against electrical discontinuity, as well as reducing the electrical resistance of an array. As shown in Figure 2, two retaining straps were welded to the conductor bars, and cast into the anode so that the straps projected from the anode on each side.

Experience in fitting the earlier patterns of anodes with copper conductor bars has shown that brazing is a considerably less common operation in a shipyard than welding, as operators for the latter are always available. It also was thought that scrap recovery might be possible if steel were used, while it would be more difficult if copper conductors were present.

One of the first installations of this type of anode was made on *HMCS Wallaceburg* in October of 1950. Enough magnesium had been installed for a two-year life, but the ship was docked for inspection at the end of one year. The appearance of the anodes is shown in Figures 3 and 4. Deep necks, that threatened to cut through the anode, had developed in the vicinity of the retaining straps while, at the same time, part of the original surface was still present near the center of the anode. The close coupling of the magnesium and steel at the straps could not be completely responsibility for the necking, as this action is not observed to any great extent around the crossbar and core pipe in the Mark I anode. In an effort to determine the cause of this inefficient behavior, a new anode was sectioned and analyzed chemically. The sections cut are shown in Figure 5.

Results of Iron Analysis

It was first thought that iron from the retaining straps and conductor bars may have been the cause of the accelerated corrosion in the crossbar areas. Figure 6 gives the distribution of iron found in the surface D-D, and Figure 7 the distribution found in the surface E-E of Figure 5.

Discussion of Iron Analyses

It is apparent that there is no great concentration of iron in the vicinity of the retaining straps and conductor bars. On the top surface, there are two samples with iron higher than normal. This could be caused by contamination from the mould. The other high iron samples were near the center of the casting and in an area that had not yet been reached by corrosion of the anodes as they appeared at the one-year docking of *Wallaceburg*. While it is not desirable to have high iron areas, they could not have been responsible for the highly accelerated attack at the straps in this test. Examination of the cut faces of the anode showed that these high iron samples were taken from an area that had a high concentration of casting pores. Thus, this metal was obviously the last to solidify and is a concentrate of the impurities of the original metal. On solidification, inward from the mould face, the impurities were pushed forward to the center of the casting. The dissolved gas was concentrated at the same location as the other impurities, and, on solidification, resulted in casting pores in the anode at the position of the impure metal.

From the foregoing it was concluded that iron impurity was not a major cause of the behavior at the anode straps. As other impurities were not likely to be present in sufficient quantity to cause trouble, further analyses for major alloying constituents were made to determine their distribution in the anode.

Analyses for Alloying Constituents

The samples for alloying constituent analyses were taken at surface F in Figure 5. The results are given in Table 1.

The analyses show that these Mark III anodes, as cast, were segregated in an inverse way. Generally the first metal to solidify in any melt, (i.e. the metal on the outside of the casting) has a higher percentage of the major constituent than the average composition of the melt from which it was derived. In this magnesium alloy casting, however, the reverse was found to be true. The highest magnesium content was found to be on the inside of the casting. This is a typical inverse segregation effect.

Since the Mark III anode is a chill casting, it seemed advisable to make similar analyses for segregation on sand cast anodes. The anode used in this case was a solid cylinder intended for use on the condenser doors of steam driven ships. It had been scalped at the foundry to 5½ inches in diameter; thus the outside samples were not available for analysis. A series of samples was taken along a radius and analyzed for major constituents. The analyses are given in Table 2.

Figure 1—A Mark I (sand cast) anode. Corrosion occurred here uniformly, with little or no tunneling from local action at the bare steel core or cross bar.

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* Naval Research-Dockyard Laboratory, HMC Dockyard, Halifax, Nova Scotia, Canada.

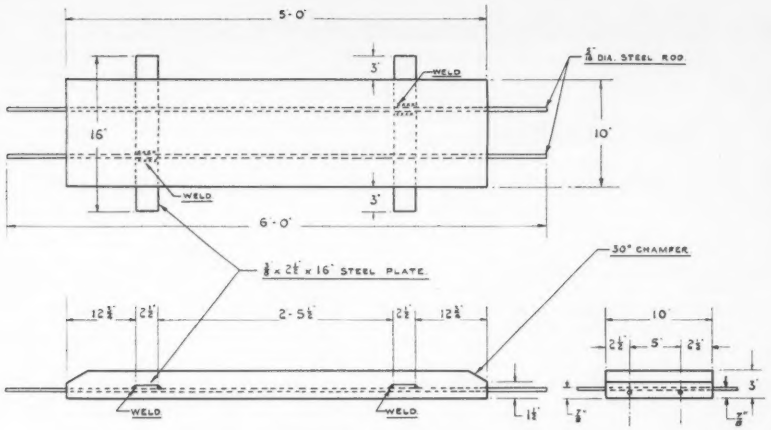

Figure 2—Layout of the Mark III (chill cast) anode.

TABLE 1—Analysis of a Chill Cast Mark III Anode for Major Constituents

Sample Number	Al	Zn	Mn	Mg. (by diff.)
1 (Top Surface)	6.95	3.52	.30	89.23
2.....	5.83	3.50	.29	90.38
3.....	5.50	3.23	.28	90.99
4.....	5.36	3.05	.32	91.27
5.....	5.34	3.09	.32	91.25
6.....	5.41	3.10	.32	91.17
7.....	5.50	3.48	.31	90.71
8 (Bottom Surface)	5.73	3.58	.31	90.38

TABLE 2—Analysis of a Sand Cast Condenser Door Anode for Major Constituents

Sample Number	Al	Zn	Mn	Mg. (by diff.)
1 (Outside)	5.63	3.12	0.42	90.83
2.....	5.57	3.14	0.60	90.69
3.....	5.72	3.10	0.58	90.60
4.....	5.55	3.08	0.49	90.88
5.....	5.62	3.09	0.53	90.76
6.....	5.46	3.19	0.49	90.86
6 (Center)	5.66	3.39	0.52	90.43

It is apparent from these results that segregation in this anode has been very slight indeed and suggests that the inverse segregation observed in the Mark III anode is associated with the chilled casting.

Electrochemical Behavior of Segregated Material

The electrochemical potential of a magnesium alloy, and probably its anodic polarization as well, will alter with varying amounts of alloying metals. In the case of a segregated casting, this means that if metal having a low alloy content and a high alloy content in different areas is used as an anode, the low alloy metal will react faster, since it will have, in general, a more anodic potential. In the case of an inversely segregated anode, this means that at any point where the surface is punctured, the action will continue there preferentially, due to exposure of a more highly anodic material. This was thought to be the probable explanation of the corrosion pattern observed in the Mark III anode.

An effort was made to measure the potential difference existing between the inside and outside metal of the segregated anode, but no consistent difference could be found in quiet sea water with no anodic current being drawn from the metal.

Description of Electrochemical Experiments

The following test was made to study the behavior of this anode metal when a current is being delivered and both outside (high alloy content) and inside (low alloy content) metal are exposed at the same time.

A block of metal was cut from the anode in a direction perpendicular to the wide face of the anode and as close as possible to the position where the samples of Table 1 were taken. It was hoped that, in this way the composition of the metal could be represented by the chemical analysis of the metal from the adjacent chemical analysis sample point.

The position of the metal block is shown in Figure 5. The block of metal was removed and machined to uniform rectangular cross section, approximately 1 cm on a side. The length was 3 inches (the thickness of the anode). This machined bar was then cut into sections to expose surfaces whose location in depth in the anode was known and whose chemical composition could be assumed known. These cubes were mounted individually in bakelite in a metallurgical specimen mounting press, to expose a known face of approximately 1 sq cm area, the remainder of the specimen being masked. The back of the bakelite mount was drilled, tapped and fitted with a bolt to provide an electrical connection to the magnesium. Eight mounted magnesium specimens were used as anodes in parallel to provide current to a common cathode. Figure 8 is a general layout of the apparatus used and a sketch of a mounted specimen. The total electrical resistance from specimen face to the common point was constant to ±0.03 ohm. The electrical connections are given in Figure 9.

Before use, the anode blocks were filed flat, finished with 2/0 metallographic emery paper, and etched 1 minute in 0.1N hydrochloric acid. They were then immersed in sea water at a uniform distance from the cathode.

If there were any inherent difference between the potential-polarization characteristics of the different anodes, it would show up as a difference in the amount of current delivery by the anodes to the common and symmetrically located cathode.

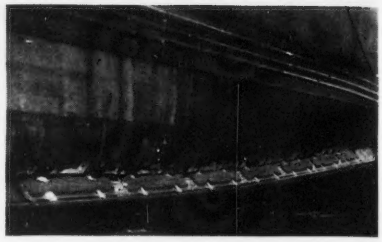

Figure 3—Typical performance of a Mark III (chill-cast) anode.

Figure 4—Tunneling at the straps in a Mark III anode.

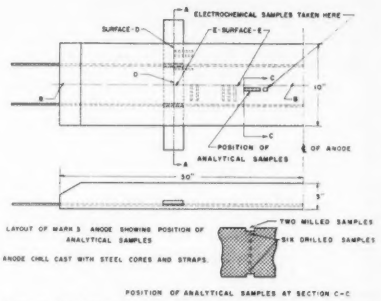

Figure 5—Sectioning of a Mark III anode for chemical analyses and electrochemical evaluation.

The mounted specimens were connected in parallel through identical resistances so that the current delivered by each depended on the total current in the common circuit, and on the potential and polarization characteristics of the individual anodes.

On an active segregated Mark III anode, the anodes in parallel are represented by different areas on the same large block of metal and are connected by a very low resistance path through the anode itself. This would have the effect in practice of accentuating any difference in anode behavoir found in the laboratory (tests where the metal representing different areas on the anode are connected through the 10 ohm resistances used to measure current output.)

Current delivery from the anodes was measured by reading the potential drop across an accurate resistance of 10 ±.02 ohm. A Leeds and Northrup type K-2 potentiometer was used. After any alteration in the total current, a 30 minute period was allowed for the anodes to come to equilibrium before current measurements were recorded. In order to maintain an active surface similar to that of a working anode, all readings were taken on the same set of samples without repolishing. Five sets of individual current readings were taken for each total current setting to obtain a reliable individual anode current. This

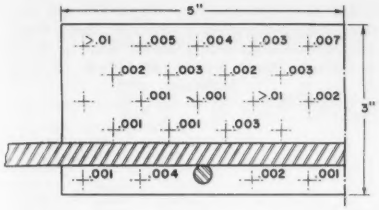

Figure 6—Iron analyses on surface D-D.

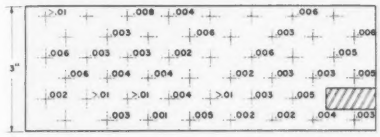

Figure 7—Iron analyses on surface E-E.

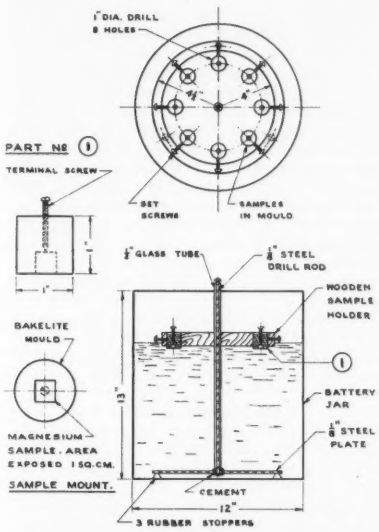

Figure 8—Apparatus used for current distribution from anodes in parallel.

was repeated on three successive days, the duration of the experiment. For each total current setting, therefore, 15 current readings on each anode were averaged to obtain the current delivered by the individual anodes. During the waiting period between daily readings, an average current density of about 0.12 amp per sq ft was drawn from the group. The current density for a Mark III anode in service varies between 0.1 amp and 1.5 amp per sq ft.

The current from the individual anodes was calculated as a percentage of the total current in the common circuit for each total current used. Since there were eight anodes in parallel, each anode would be expected to deliver 12.5 percent of the total current, if the anodes were identical.

Results of Electrochemical Experiments

In Table 3 are listed the averages of the fifteen current readings in milliamperes from the separate anodes. The mean of the current densities of all the anodes also has been included, calculated as milliamperes per sq cm and as amperes per sq ft based on 0.98 sq cm area per anode. These current densities roughly represent very low, medium,

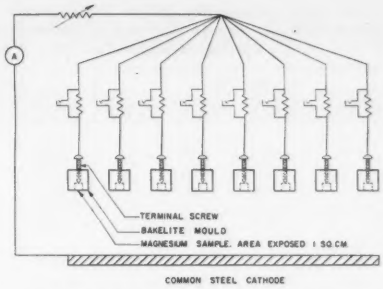

Figure 9—Electrical connections for the determination of current distribution from anodes in parallel.

TABLE 3—Mean Current Delivered by Individual Anodes at Three Total Current Settings

Sample No.	External Current (ma) 0.5	4.0	15.0
1	0.033	0.428	1.83
2	0.040	0.488	2.00
3	0.094	0.559	1.93
4	0.118	0.593	1.96
5	0.107	0.588	2.01
6	0.071	0.513	1.75
7	0.031	0.457	1.87
8	0.021	0.372	1.74
Totals	0.515	3.998	15.08
Mean Current Density ma/sq/cm	0.066	0.510	1.92
Mean Current Density amp/sq ft	0.061	0.475	1.79

and high rate of consumption of the anode material. There is a reasonably close agreement between the measured current in the external circuit and the total obtained as the sum of the eight current values in Table 3.

Table 4 is a calculation of the percentage of the total current delivered by each anode at three current densities.

Figure 10 is a plot of the percentage of the total current delivered as ordinates against the position of the sample in the anode as abscissa. Chemical analyses are also included on this graph.

Discussion of Experimental Results

Figure 10 demonstrates the fact that the material richest in magnesium is most anodic while that highest in alloying constituents is most cathodic, the differences in behavior being most marked at low current densities. With these facts in mind, it was suggested to the company casting the anodes that the casting technique be altered to minimize the segregation. Some changes were made in the casting technique and one of the anodes so produced was analyzed for segregation of major constituents and tested for distribution of anode current from anodes in parallel, using the technique described above.

The chemical analysis obtained are given in Table 5. Sampling was according to Figure 5.

The percentage current distribution for eight small anodes in parallel is given in Table 6.

These values in Tables 5 and 6 are plotted in Figure 11. A slight difference in the cross sectional area of the milled specimen caused the slight differences in average current density between Tables 4 and 6.

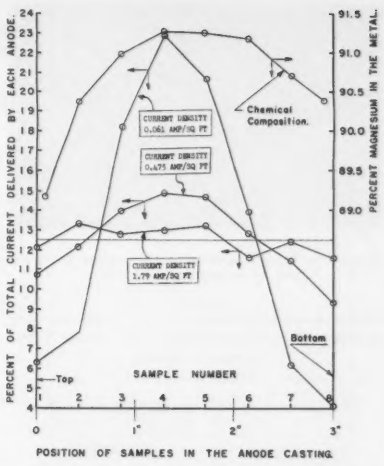
PERCENT OF TOTAL CURRENT DELIVERED BY EACH ANODE.
PERCENT MAGNESIUM IN THE METAL.
Chemical Composition.
CURRENT DENSITY 0.061 AMP/SQ FT
CURRENT DENSITY 0.475 AMP/SQ FT
CURRENT DENSITY 1.79 AMP/SQ FT
Top
Bottom
SAMPLE NUMBER
POSITION OF SAMPLES IN THE ANODE CASTING

Figure 10—Chemical analyses and current distribution from anodes in parallel obtained using metal from a chill cast Mark III anode.

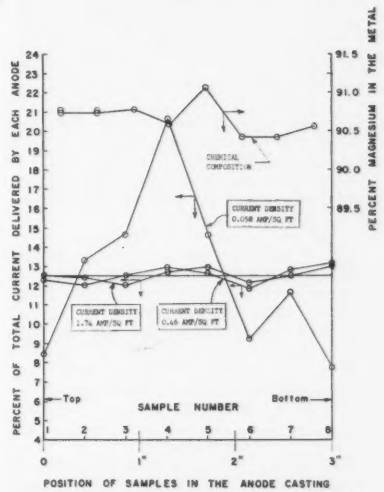
PERCENT OF TOTAL CURRENT DELIVERED BY EACH ANODE
PERCENT MAGNESIUM IN THE METAL
CHEMICAL COMPOSITION
CURRENT DENSITY 0.058 AMP/SQ FT
CURRENT DENSITY 1.76 AMP/SQ FT
CURRENT DENSITY 0.46 AMP/SQ FT
Top
Bottom
SAMPLE NUMBER
POSITION OF SAMPLES IN THE ANODE CASTING

Figure 11—Chemical analysis and current distribution from anodes in parallel obtained using metal from a Mark III anode cast by a modified technique.

Discussion of Results

Comparison of Figures 10 and 11 shows that at very high current density there is little tendency for either anode to develop a poor corrosion pattern on the basis of current output alone.

At an overall anode current density of about 0.5 amp sq/ft the less segregated casting shows a distinct superiority and gave a current distribution not far different from that obtained at 1.75 amp/sq ft. The highly segregated anode shows a maximum value of 1.5:1 for the ratio of current output of the most active metal (sample 4) to the least active (sample 8). For the less segregated anode the maximum ratio is 1.1:1 for samples 8 and 6, at the same current density.

At the very low current density of approximately 0.06 amp/sq ft, which is seldom used for long periods in hull protection, both anodes show differences in current output from most active to least active metal. Even here, however, the less segregated anode shows a distinct improvement over the more highly segregated one. The ratio

Figure 12—Typical performance of a Mark III anode cast by a modified technique.

TABLE 4—Percentage of the Total Current Delivered by Each Anode for Three Total Current Settings

Sample No.	Percent of Total Current for Anodes of Three Mean Current Densities		
	0.061 amp/sq ft	0.475 amp/sq ft	1.79 amp/sq ft
1	6.3%	10.7%	12.1%
2	7.8%	12.2%	13.3%
3	18.2%	14.0%	12.8%
4	22.9%	14.9%	13.0%
5	20.7%	14.7%	13.2%
6	13.9%	12.8%	11.6%
7	6.2%	11.4%	12.4%
8	4.1%	9.3%	11.6%

of current output from most active to least active is 2.7 for the former and 5.5 for the latter. It is possible that at these low current densities that the current distribution may depend on metallurgical factors in addition to the segregation of major alloying constituents.

Although extended service results of the anodes cast by the modified casting method are not available some ships carrying these anodes have been inspected. Figure 12 shows the appearance of some of the Mark III anodes cast by the modified casting technique as they appeared after six months service.

Conclusions

The results obtained with the experimental set-up indicate very strongly that the following mechanism may be the cause of the necking observed in the original Mark III anode. Close coupling of steel to magnesium alloy at the cross bar causes a slightly increased attack on the anode in the vicinity of the bar, above the general attack over the surface produced by the normal operation of the anode. The increased attack near the bar exposes metal that is more anodic, while delivering current, than the remainder of the anode surface. The general attack therefore will shift, in part, from the anode surface and concentrate at the more anodic metal that is being exposed in the interior of the anode near the bar, producing the neck observed in practice. When the attack has progressed at the neck far enough to expose the center metal that is the most highly anodic and at the same time has the highest concentration of heavy metal impurities (iron for example as shown by analysis), the attack on the anode will be further increased due to self corrosion of the more impure (as distinct from more highly alloyed) metal.

Evidence of this behavior has been observed on some anodes. With the attack on the more active material, increase in size of the opening in the anode surface will occur which in turn will lower the sea path resistance and allow the attack to proceed.

The active ship anodes described in this report all have been used in controlled protection systems. With this type of operation it is possible to install enough magnesium on a ship to provide complete protection for a period of two years or more. In this way work of renewal of anodes and lay days in dock are reduced to a minimum and full advantage is taken of the economies that are available with cathodic protection.

TABLE 5—Analysis for Major Constituents on a Mark III Anode Cast by a Modified Casting Method

Sample Number	Al	Zn	Mn	Mg. (by diff.)
1 (Top Surface)	6.12	2.68	.37	90.73
2	5.90	2.97	.40	90.73
3	5.91	2.94	.38	90.77
4	6.08	2.89	.44	90.59
5	5.72	2.78	.45	91.05
6	6.10	3.00	.48	90.42
7	5.90	3.08	.61	90.41
8 (Bottom Surface)	6.00	3.00	.45	90.55

TABLE 6—Percentage of Total Current Delivered by Individual Anodes at Three Total Current Settings Using Metal from a Mark III Anode Cast by a Modified Casting Method

Sample No.	Percentage of Total Current At Three Mean Current Densities		
	0.058 amp/sq ft	0.464 amp/sq ft	1.74 amp/sq ft
1	8.4%	12.3%	12.5%
2	13.3	12.0	12.4
3	14.6	12.5	12.0
4	20.6	12.9	12.7
5	14.6	12.6	12.9
6	9.2	11.8	12.1
7	11.6	12.8	12.5
8	7.7%	13.1%	13.0%

Operation of a controlled system, whether complete control is used with a variable resistance and metering equipment installed inboard or only partial control with fixed resistances installed with each anode, will limit the current output of the anode and allow the effect of any inverse segregation to become evident.

Several steps may be taken to minimize the necking. Galvanizing or aluminum coating the cast-in steel inserts will reduce the potential causing the initial penetration of the anode surface. Alterations in casting technique have produced an anode that is less highly segregated than those previously in use and service trials of this anode appear promising. Further alteration in the casting technique may allow advantage to be taken of the inverse segregation effect to produce anodes with an active outer surface and with less active metal in the vicinity of the conductor bars and retaining straps which then will be the last to be consumed.

Acknowledgments

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Any discussions of this article not published above will appear in the December, 1958 issue

Corrosion of Steel in Water By Varied Ratios of Dissolved Gases*

By J. WADE WATKINS[1] and G. W. KINCHELOE[2]

Abstract

Laboratory tests were made to determine the corrosivity of steel in water containing varying concentrations of dissolved gases. Tests were conducted with varied ratios of free carbon dioxide to both oxygen and hydrogen sulfide, with the concentration of one gas maintained constant throughout a series of tests and the concentration of the other gas varied by increments to values approaching saturation. Corrosion rate as a function of time in the system was determined at time intervals to a maximum of 984 hours exposure. Results indicated that corrosion caused by oxygen and free carbon dioxide increased almost in direct proportion to the concentration of dissolved oxygen. The greatest potential corrosion in a water-injection system might be expected from water saturated with air and containing high concentrations of dissolved free carbon dioxide. The inhibiting action of hydrogen sulfide by the formation of protective coatings was manifested almost throughout the entire range of carbon dioxide-hydrogen sulfide ratios. In the time versus corrosion tests, the corrosion rate was fairly linear with time up to about 72 hours; it then increased, and again assumed a nearly linear relationship from about 140 hours to 984 hours exposure. 3.4.6

Introduction

THE CORROSION of steel equipment in oil-production systems has been a problem of economic concern since the early days of the industry. This problem is intensified in stimulative methods of petroleum production by water injection, particularly when the waters injected have high concentrations of dissolved salts and gases. Although electrochemical corrosion is intensified markedly in strong electrolytes, such as oil-field brines, the principal basic corrosive agents in injection waters are the common dissolved gases: oxygen, free carbon dioxide, and hydrogen sulfide. In an earlier paper,[1] data were presented on the corrosion caused to mild carbon steel in distilled water by concentrations of those three dissolved gases ranging from zero to near saturation values.

Additional laboratory tests were made with varied ratios of free carbon dioxide to oxygen and hydrogen sulfide, with the concentration of one gas maintained constant throughout a series of tests and the concentration of the other gas varied by increments to values approaching saturation. Data derived from six series of dissolved-gas corrosion tests of 72 hours duration are presented herein. Results of one test of corrosion rate versus time with a maximum of 984 hours exposure also are presented. Experimental methods are summarized, and the method used for quantitatively determining free carbon dioxide in the presence of appreciable concentrations of hydrogen sulfide is described.

Apparatus

The apparatus employed for the tests described herein was essentially the same as that described earlier by Watkins and Wright.[1] All tests were conducted using a non-metallic dynamic system. Corrodent gases were dissolved in distilled water with the temperature, concentrations of dissolved gases, and flow velocity stabilized and controlled. Duplicate systems were used so that two corrosion-test runs might be made simultaneously.

Corrosion specimens 35 mm wide and 50 mm long were cut from mild-steel shim stock 1 mm thick. Results of earlier laboratory tests indicated that more reproducible results were obtained by using shim stock than by using sheet steel, which is less uniform in composition.

The corrosion specimens were precorroded in a solution of 10 percent ammonium citrate and 10 percent ammonium hydroxide at 55 C for one hour to prevent erroneous initial weight losses caused by irregularities in the surface finish of the steel. The precorroded specimens then were scrubbed with water and scouring powder by using a stiff brush, were rinsed with distilled water followed by acetone, and then were air dried, weighed, and stored in a desiccator over a drying agent until they were used.

Test Method

Before a corrosion test was made, water was cycled through the apparatus until a constant operating temperature of 80 F (about 26.7 C) was attained. After the temperature was stabilized, gas was dispersed into the water, and cycling was continued until the desired gas concentration remained constant. One gas (for example, carbon dioxide) was dispersed into one saturator, the second gas (for example, oxygen or hydrogen sulfide) was dispersed into a second saturator, and the ratio of concentration of the gases was controlled by the dispersion of nitrogen into the third saturator.

When stability of the gas concentration was obtained, the corrosion specimens were placed in jars and exposed for a period of 72 hours. During this time the temperature of the corrodent was maintained with an average deviation of 0.2 F and a maximum deviation of 0.5 F. The pH of the solution was recorded continuously, and samples of the water taken at intervals were analyzed to determine quantitatively the concentrations of dissolved gases. Pressure-regulator valves were adjusted as necessary to maintain the desired gas concentrations. The velocity of the fluid past the test specimens was maintained close to 0.05 centimeter per second.

At the conclusion of a test the specimens were removed from the jars and inspected, and the nature and quantity of corrosion products were recorded. The specimens were wiped to remove loose corrosion products from the surface, scrubbed again as previously described, and placed in a solution of 10-percent ammonium citrate and 10-percent ammonium hydroxide at 55 C for one hour. At the end of this interval, the specimens again were scrubbed, rinsed in distilled water and acetone, air dried, and weighed to determine the loss in weight. One non-corroded specimen was cleaned in the same manner and for the same length of time as the corroded specimens to determine the loss in weight caused by cleaning alone. This loss was deducted from the total weight loss of each specimen, and the difference in weight loss was considered to be caused by corrosion. Four to seven specimens were used in each corrosion test, and an average of the weight losses was used as the value for corrosion loss at that particular gas concentration. These values were converted from milligrams per specimen to average penetration per year in thousandths of an inch (mpy).

Oxygen-Carbon Dioxide Corrosion

The results of three series of corrosion tests presented graphically in Figure 1 show the magnitude of corrosion to steel caused by concentrations of free carbon dioxide ranging from 20 to 670 ppm at oxygen concentrations of 1.6, 4.3, and 8.8 ppm.

The pH value ranged from 4.1 to 4.8 throughout the series of tests. Visual observation of the corrosion specimens

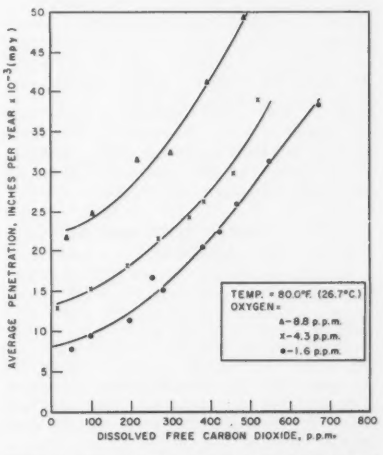

Figure 1—Corrosion of mild steel in distilled water by dissolved oxygen and free carbon dioxide.

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(1) Chemical engineer, Bureau of Mines, Bartlesville, Oklahoma.

(2) Chemical engineer, formerly with Bureau of Mines, Bartlesville, Oklahoma.

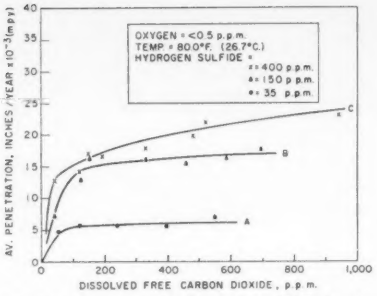
OXYGEN = <0.5 p.p.m.
TEMP. = 80.0°F. (26.7°C.)
HYDROGEN SULFIDE =
x = 400 p.p.m.
▲ = 150 p.p.m.
● = 35 p.p.m.
AV. PENETRATION, INCHES / YEAR x 10⁻³ (mpy)
DISSOLVED FREE CARBON DIOXIDE, p.p.m.

Figure 2—Corrosion of mild steel in distilled water by dissolved free carbon dioxide and hydrogen sulfide.

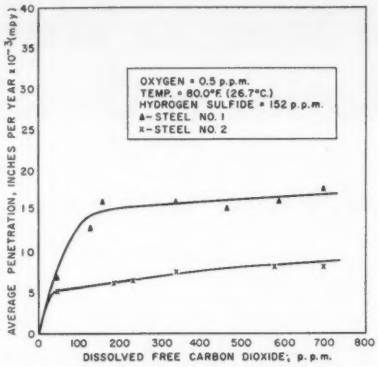
OXYGEN = 0.5 p.p.m.
TEMP. = 80.0°F. (26.7°C.)
HYDROGEN SULFIDE = 152 p.p.m.
▲ = STEEL NO. 1
x = STEEL NO. 2
AVERAGE PENETRATION, INCHES PER YEAR x 10⁻³ (mpy)
DISSOLVED FREE CARBON DIOXIDE, p.p.m.

Figure 3—Comparative corrosion of mild steel of different composition by dissolved free carbon dioxide and hydrogen sulfide.

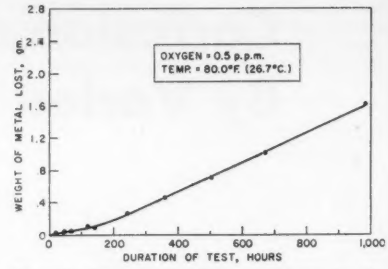

Figure 4—Corrosion of mild steel in water by dissolved free carbon dioxide as a function of exposure time.

at the end of each test showed that the specimens were spotted with a loose, yellow to red, porous coating of an iron oxide. The amount of iron oxide present and the extent and depth of pits observed on the surfaces of cleaned specimens were roughly proportional to the concentrations of dissolved oxygen used in each test. A continuous black coating, tentatively identified as an intermediate iron oxide, was observed under the loose yellowish-red oxide coating. Corrosion products were not analyzed. At lower concentrations of carbon dioxide, the coating was removed easily from the metal surface by scrubbing; at higher concentrations removal was much more difficult.

The shapes and slopes of the curves presented here represent a combination of the same functions of curves plotted from data indicating the corrosion caused by oxygen and free carbon dioxide solutions independent of one another. When corrosion was plotted[1] on the ordinate of rectilinear coordinates against concentration of the dissolved gas on the abscissa, the resultant curves were concave for oxygen corrosion and convex for carbon dioxide corrosion, as compared to the left vertical and upper horizontal axes. The curves in Figure 1 all exhibit a concave shape, becoming more linear at concentrations of free carbon dioxide greater than 300 to 400 ppm. The slopes of the straight-line portions of the curves are intermediate between those of the curves previously obtained for oxygen and free carbon dioxide alone.

The magnitude of corrosion was greater with both oxygen and carbon dioxide in common solution than for comparable concentrations of either gas singly. Using the same test methods, results reported earlier showed a maximum corrosion weight loss of 9.5 mpy for oxygen (8 ppm.) and 29 mpy for free carbon dioxide (750 ppm). The maxima indicated in Figure 1 are 38 mpy at 670 ppm carbon dioxide and 1.6 ppm oxygen; 39 mpy at 550 ppm carbon dioxide and 4.3 ppm oxygen; and 49 mpy at 480 ppm of carbon dioxide and 8.8 ppm of oxygen.

Carbon Dioxide-Hydrogen Sulfide Corrosion

Figure 2 shows the corrosion rates for mild steel exposed to an aqueous solution containing 35 to 940 ppm free carbon dioxide with hydrogen sulfide concentrations averaging 35, 150, and 400 ppm In all three tests dissolved oxygen content was less than 0.5 ppm. The pH of the solution ranged from 4.0 to 5.1 throughout the three series of tests.

In the corrosion data previously published[1] it was shown that corrosion increased sharply with increased concentrations of dissolved hydrogen sulfide up to a concentration of about 150 ppm. From 150 ppm to about 400 ppm, corrosion remained essentially constant and between 400 and 1,600 ppm corrosion diminished rapidly. From 1,600 ppm to 2,640 ppm the corrosion rate again became nearly constant. Little more corrosion occurred in this concentration range than at 5 to 10 ppm. It was theorized that polysulfides or other complex iron sulfide compounds formed at the higher concentrations of hydrogen sulfide inhibited corrosion by passivation of the metallic surface of the specimens. This belief was borne out by laboratory tests using ammonium polysulfide as an inhibitor which noticeably reduced corrosion of the inhibited specimens.

On the basis of the earlier experiments it was expected that hydrogen sulfide might exhibit an inhibiting effect at relatively high concentrations when in common solution with carbon dioxide. The data presented in Figure 2 show that an inhibiting action was obtained. However, instead of occurring at high concentrations of hydrogen sulfide only, inhibition apparently took place also at lower concentrations. For example, curve A of Figure 2 shows little increase in corrosion with increasing carbon dioxide concentration. This is not comparable to the results obtained with carbon dioxide alone or in common solution with oxygen. The maximum corrosion obtained with a hydrogen sulfide concentration of 150 ppm (curve B, 17 mpy) is less than the maximum obtained with hydrogen sulfide alone at that concentration (26 mpy), as previously reported.[1] The maximum corrosion with a hydrogen sulfide concentration of 400 ppm (curve C, 23 mpy) is less than the maximum with hydrogen sulfide alone at that concentration (26 mpy). The flat slope of all three curves indicates that some inhibition occurred throughout the tests.

Surfaces of the specimens used in the hydrogen sulfide-carbon dioxide corrosion test were covered with a precipitated black coating in varying degrees of density and thickness. As in earlier tests with hydrogen sulfide alone, the relative thickness of the corrosion product increased with increases in hydrogen sulfide concentration; however, the bulk of the material was comparatively easily removed. At higher concentrations of hydrogen sulfide an extremely tenacious, uniform, dark coating that formed next to the surface of the metal apparently was more dense and much more difficult to remove. This coating apparently was responsible for inhibition of corrosion throughout the three series of tests, and particularly so at the higher hydrogen sulfide concentrations. As in the earlier tests, this coating was considered to be a complex sulfide.

The problem of identifying the various sulfides formed during the corrosion of steel by hydrogen sulfide in various aqueous environments, and of evaluating the relative effect on corrosion rates of the respective sulfides, is an exceedingly complex one which has been studied by numerous investigators. Meyer et al[2] presented a comprehensive review of the identification and effect of various sulfide corrosion products, in which they reported that, in a distilled-water-hydrogen-sulfide system, kansite (Fe_9S_8) tarnish apparently inhibited, whereas kansite scale accelerated corrosion, with subsequent lessening of corrosion rates as the Fe_9S_8 was converted successively to pyrrhotite (Fe_7S_8) and pyrite (FeS_2). Their results further showed that, in a brine system, the kansite scale continued to form, with a continued increase in corrosion rates with time and that the presence of carbon dioxide appeared to inhibit the subsequent formation of pyrrhotite and pyrite.

Although the corrosion products formed during the tests reported herein were not identified, the coating next to the metal at the higher concentrations of hydrogen sulfide in distilled water and throughout the series of tests with both hydrogen sulfide and free carbon dioxide in distilled water had more of the appearance of a tarnish than a scale. The authors of this paper suggest that this substance may have been kansite tarnish, as shown to be responsible for the inhibition of corrosion during the first 3 to 9 days of the tests reported by Meyer et al.

Skei and Bonner were issued a patent[3] on a method of preventing hydrogen blistering and fissuring by the use of polysulfides in aqueous systems introduced either externally or formed in place by the addition of oxidizing agents. However, they teach that polysulfides are destroyed in acid environments. In the experiments reported herein, the pH of the system always was on the acidic side. Nevertheless, definite inhibition was observed through the action of the precipitated corrosion product.

Effect of Composition of Steel Alloy on Corrosion Rate

At an intermediate point in the corrosion-test program, it became necessary to obtain a new supply of the shim stock from which the corrosion speci-

TABLE 1—Spectrographic Analyses of Steel Corrosion Specimens

ELEMENT	Minor Constituents, Present Percent	
	Steel No. 1	Steel No. 2
Chemical carbon	0.24	0.06
Manganese	.39	.31
Chromium	.03	.01
Nickel	.06	.025
Copper	.17	.55

mens were prepared. Although it was recognized that minor variations in composition of the two steel alloys might cause minor differences in their relative corrosion resistance, it was not believed that the difference in resistance would be of appreciable magnitude. However, it was determined that the corrosion resistance of the two steels differed more than was expected. Figure 3 is a plot of the corrosion caused to the two steels by comparable concentrations of free carbon dioxide (50 to 700 ppm) and hydrogen sulfide (150 ppm). It may be observed that the corrosion caused to steel No. 1 is approximately three times that caused to the new steel. The results of spectrographic analyses of the two steels are presented in Table 1.

It is of interest that the more corrosion-resistant steel contained less carbon, manganese, chromium, and nickel and more copper than the other steel, which was more severely corroded. Manganese, chromium, and nickel apparently did not afford corrosion protection, whereas copper did for the particular environment of carbon dioxide and hydrogen sulfide used in the test. All of the tests reported in Figures 1, 2, and 4 of this paper were made with the copper-bearing, more resistant steel. The composition of this steel more nearly approaches that of the steel commonly used for the fabrication of oil-field equipment. However, considering the difference in the magnitude of corrosion that can be caused by minor variations in constituents of the steel, it is recognized that generalizations should not be made as to the relative corrosion resistance of mild steels in actual service.

Extrapolation of Results of 72-Hour Test to Longer Periods

The 72-hour period of exposure was selected arbitrarily as being an exposure time that should yield results that might be extrapolated to field conditions for predicting the life of steel tubular goods and other production equipment. To determine the linearity of the relationship of corrosion to exposure time and the validity of extrapolations of data obtained from comparatively short-range tests, an extended corrosion test was made, using a solution with a constant concentration of 510 ppm of free carbon dioxide and 0.5 ppm of oxygen as the corrodent. Ten corrosion specimens were placed in the solution and one specimen was removed at intervals of multiples of 24 hours over a range of time extending from 24 hours to 984 hours.

Data from the test are plotted in Figure 4 as a function of weight loss versus hours of exposure. Corrosion was fairly linear with time up to about 72 hours. The rate then increased and again assumed a linear relationship from about 140 hours to 984 hours.

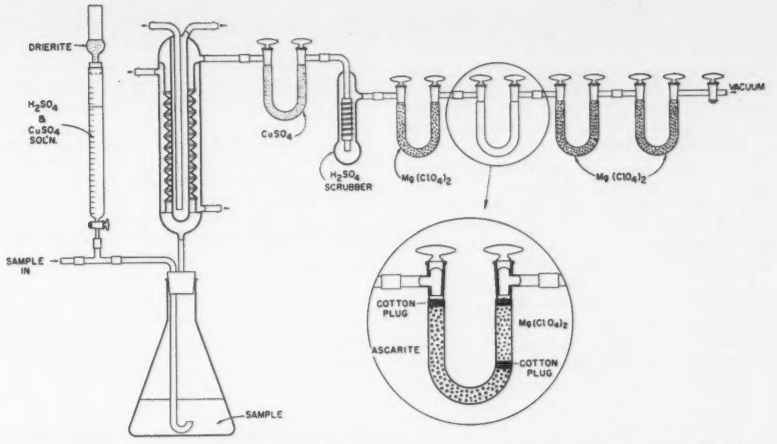

Figure 5—Apparatus for determination of carbon dioxide by the evolution method using solid absorbents.

These data indicate that extrapolation of the results of 72-hour corrosion tests to longer exposure times requires weighting of the calculated corrosion data. A more severe corrosion rate may be predicted after 100 plus hours under conditions comparable to those of these particular tests.

It is significant that the corrosion rate did not lessen with increased time for the system containing a constant concentration of dissolved free carbon dioxide and no other appreciable contents of either dissolved gases or mineral salts. In an actual injection-water system, the rate of corrosion would not be expected to be as linear as that indicated in Figure 4.

One of the factors used in converting weight loss to average penetration in inches (or mils) per year is the duration of the test in time units. The graph in Figure 4 indicates that the mpy values derived by converting weight losses from the 72-hour tests should be weighted by an appropriate factor to indicate more severe corrosion. However, the source of error inherent in the extrapolation of short-range tests should be much less than that resulting from the assumption that weight loss may be converted to an average-penetration value and this value used to predict pipe failure. Much of the corrosion caused by dissolved gases is localized rather than uniform. The pitting of oxygen corrosion and the hydrogen-blister formation of hydrogen sulfide corrosion may be disproportionately severe as compared to weight-loss measurements. Although average-penetration values are a convenient method of reporting corrosion results, it should be remembered that pipe failure may occur much more rapidly than is indicated by average-penetration values calculated from weight-loss rates. Predicting pipe failure by an average penetration value presupposes that corrosion is uniform throughout the entire length of pipe. This, of course, is not true because of localized corrosion.

Quantitative Determination of Free Carbon Dioxide in the Presence of Hydrogen Sulfide

A titrimetric method[4] of determining free carbon dioxide in aqueous solution was used in earlier tests when varied ratios of free carbon dioxide and oxygen were used as the corrodents. When appreciable concentrations of hydrogen sulfide were present, however, the buffering action of the sulfide invalidated the results of the carbon dioxide determination. Therefore, a solid absorbent was used for quantitatively determining carbon dioxide in the presence of hydrogen sulfide[5]. Figure 5 is a simplified flow diagram of the apparatus used for this purpose.

A 100-ml sample of the solution was introduced into an Erlenmeyer flask from an external container through a glass tube. A sulfuric acid-copper sulfate solution to inactivate hydrogen sulfide was introduced into the flask from a buret with a Drierite absorber section at the top. The sample then was heated to boiling while a reduced pressure was maintained at the outlet end of the absorption train. The evolved gas passed first through a reflux condenser and then through the first U-tube containing copper sulfate to remove any hydrogen sulfide not inactivated in the flask. The gas then passed into a scrubbing bottle, containing sulfuric acid to remove water vapor. The gas flow was regulated by a controlled partial vacuum so that the gas bubbles escaped into and rose through the hydrogen sulfide scrubber at a slow rate.

The gas next passed into a second U-tube containing magnesium perchlorate used as a drying agent and then into the previously weighed U-tube shown in Figure 5. The absorbent U-tube contained indicating Ascarite (asbestos impregnated with sodium hydroxide) and magnesium perchlorate used to protect the absorbent tube against contamination from any backflow of gases. Carbon dioxide was absorbed in the center U-tube according to the reaction: $2\ NaOH + CO_2 = Na_2CO_3 + H_2O$. The quantity of carbon dioxide absorbed was determined by weighing and was converted to carbon dioxide in parts per million. Heating was continued for an arbitrarily predetermined time (about 20 minutes) indicated by preliminary tests to give a constant weight of the absorbent U-tube. The method was calculated to be accurate and reproducible within about 10 percent at concentrations of carbon dioxide of the order of 20 ppm.

Conclusions

The following conclusions are drawn from the data presented in this paper:

1. Corrosion caused by oxygen and free carbon dioxide dissolved in distilled water increases almost in direct proportion to increases in the concentration of dissolved oxygen.

2. On the basis of results described herein, the greatest potential corrosion in a water-injection system may be expected from water saturated with air and containing high concentrations of dissolved free carbon dioxide.

3. The inhibiting action exhibited by hydrogen sulfide by the formation of protective coatings of complex sulfides is manifested almost throughout the entire range of carbon dioxide-hydrogen sulfide ratios and is even greater than with hydrogen sulfide alone. The behavior of hydrogen sulfide corrosion is not completely predictable from available data.

4. Application of the data presented herein to field conditions should be weighted to indicate a more severe corrosion rate with the substitution of brine for distilled water, the presence of galvanic potentials, and the probability of pipe or equipment failure because of severe localized corrosion. The results reported herein probably should be regarded as representing minimum corrosive conditions.

5. Further research on corrosion in the hydrogen sulfide-carbon dioxide system is warranted to permit a better understanding of the significant physical and chemical factors involved, especially at high concentrations of hydrogen sulfide.

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Any discussions of this article not published above will appear in the December, 1958 issue

Mechanism of Inhibiting Effect of Hydrofluoric Acid In Fuming Nitric Acid on Liquid-Phase Corrosion Of Aluminum and Steel Alloys*

By DAVID M. MASON[1] and JOHN B. RITTENHOUSE[2]

Abstract

The inhibiting effect of hydrofluoric acid in fuming nitric acid on the liquid-phase corrosion of aluminum alloys and iron alloys is found to be dependent primarily on the formation of a tenacious insoluble fluoride compound of aluminum or iron, respectively, on the surface of the metal. This mechanism is discussed in relation to: (1) solubility data for several pertinent compounds, (2) analysis of passivating coating on metal samples, and (3) correlation of solubility data with extent of corrosion of metal. The role diffusion plays in the passivation process is discussed briefly. Most of the measurements were made using fuming nitric acid containing 14 wt percent NO_2 and 3 wt percent H_2O, acid of this composition being thermally very stable.

3.8.3

IN PREVIOUS studies[1, 2, 3] the inhibiting effect of HF of the corrosion of aluminum and iron by both liquid- and gas-phase nitric acid was discussed. By analyzing the coatings on the metal evidence was obtained that the passivating process probably was due to the formation of a metallic fluoride precipitate on the surface of the metal, making it more impervious to corrosive attack by fuming nitric acid. This paper presents some additional experimental data substantiating this mechanism in the case of liquid-phase attack of metals by fuming nitric acid. These studies are limited to acid of a composition richest in HNO_3 and yet thermally stable,[3] although passivation has been found to be effective over a wide range of composition.[2]

The over-all liquid-phase corrosion process in the case of aluminum and iron alloys in fuming nitric acid has been shown to proceed in accordance with:

$$M + 2nHNO_3 \rightarrow nNO_2 + nH_2O + M(NO_3)n$$

where M represents the metal whose valence in the oxidized state is n. The presence of HF in the liquid phase permits the formation of insoluble fluorides by interaction with the metal ions produced by corrosion. Measurements of the solubility of aluminum nitrate, aluminum fluoride, iron fluoride, chromium fluoride, and nickel fluoride in fuming nitric acid were made as a function of temperature for use in interpreting observed cases of corrosion inhibition.

The question arises as to whether or not the entire solution need be saturated with the fluoride before passivation is effective for storage at ambient temperatures of the order of months. The ratio of surface of metal to volume of liquid would be of importance if it were necessary that the solution be saturated with respect to the fluoride. The fact that effective passivation depends on conditions of saturation was established by correlating the extent of corrosion which had taken place before passivation with the solubility data for the particular metal fluoride. Also uni-dimensional diffusion experiments measuring the concentration of metal ion products of corrosion as a function of time and distance from the metal gave confirmatory evidence as to the solubility mechanism of passivation.

Experimental Procedure

Solubility Measurements

Solubility data for various commercially obtained solid compounds were determined by saturating the liquid sample of fuming nitric acid with the particular solid and analyzing the liquid phase for the concentration of metallic species together with the concentration of fluoride when present. The solubility of solid products actually formed by the corrosion process was checked also.

The acid samples were contained in polyethylene bottles immersed in a constant-temperature bath for 48 hours. To facilitate attainment of equilibrium, agitation was maintained by means of a magnetically driven, Teflon-covered iron pellet.

Corrosion Measurements

The passivating process was followed in several cases by continuously determining the extent of corrosion of the metal by measuring the electrical resistance of a tube of the particular metal of interest immersed in the acid as a function of time.[4]

The composition of the passivating coatings was determined by exposing strips of metal with a relatively large area to volume of liquid, the passivating coatings formed being removed by abrasion and analyzed chemically. Also, the effect of concentration of hydrofluoric acid (HF) on the effectiveness of passivation was determined with strips of metal, the extent of corrosion at a given time being determined by the weight loss method.

Analytical Procedures

The metals and fluoride in FNA solution were determined colorimetrically using the Beckman DU spectrophotometer. The iron was detected by ortho-phenanthroline and aluminum with eriochrome cyanine. The chromium was analyzed in potassium hydroxide solution, the nickel was determined with dimethyl glyoxime while the fluorine was determined with alizarin sodium sulfonate-$(ZrNO_3)_4$.

Results

Solubility Measurements

Aluminum compounds. The aluminum and iron corrosion products for these measurements were obtained by reacting the commercially pure metal with FNA until saturation of the acid with metal salts was accomplished. The remaining FNA was boiled off and fresh acid of composition 14 percent NO_2 and 3 percent H_2O (balance HNO_3) was added to the metal/metal-corrosion-product mixture. The solution was brought to the temperature indicated in Table 1 and a sample was analyzed for the amount of metal in solution in the acid.

The concentration of aluminum in solution with the solid phase thus formed *in situ* by corrosion of pure aluminum is shown as a function of temperature in Table 1 and Figure 1. Shown for comparison is the concentration of iron in solution in FNA formed similarly. It is evident that the solubility of the iron in FNA is much less affected by tempertaure than is the solubility of the aluminum. The precipitated solid phases were not identified although hydrated aluminum nitrate is probably

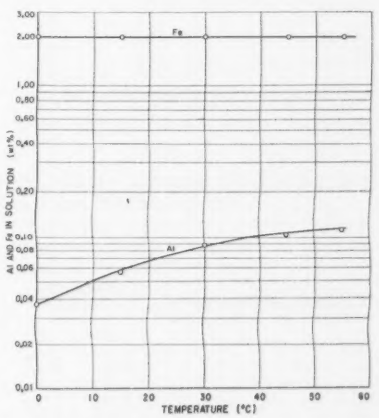

Figure 1—Concentration of Al or Fe in fuming nitric acid solution saturated with metal nitrate.

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(1) Chairman of Division of Chemical Engineering, Stanford University; formerly with Jet Propulsion Laboratory, California Institute of Technology.

(2) Research Specialist, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California.

(3) Throughout this report results pertain to fuming nitric acid (the ternary system HNO_3-NO_2-H_2O) of the particular composition 14 wt percent NO_2 and 3 wt percent H_2O. In this composition range the acid is thermally very stable.

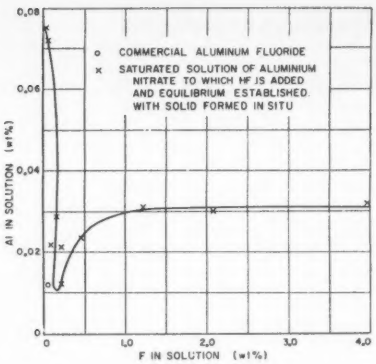
o COMMERCIAL ALUMINUM FLUORIDE
× SATURATED SOLUTION OF ALUMINUM NITRATE TO WHICH HF IS ADDED AND EQUILIBRIUM ESTABLISHED WITH SOLID FORMED IN SITU
Al IN SOLUTION (wt%)
F IN SOLUTION (wt%)

Figure 2—Concentration of Al and F in fuming nitric acid saturated with aluminum-fluoride compound at 25 C.

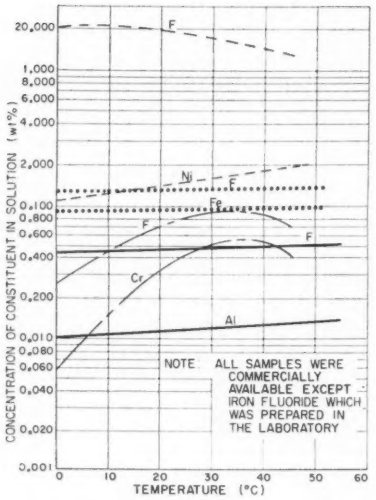

Figure 3—Concentration of the various metallic ions and fluoride in fuming nitric acid saturated with corresponding metal-fluoride compound.

TABLE 1—Concentration of Al or Fe in Fuming Nitric Acid Solution Saturated with Metal Nitrate by Solution of the Metal

Temperature (Degrees C)	Metal in Solution[a] (Wt. Percent)	
	Al	Fe
0	0.037	2.0
15	0.057	2.0
30	0.087	2.0
45	0.103	2.0
55	0.113	2.0

[a] Fuming nitric acid containing initially 14.0 wt. percent NO_2, and 3.0 wt. percent H_2O. The remainder is HNO_3.

the equilibrium solid phase in the case of aluminum and either hydrated ferrous or ferric nitrate in the case of iron. There is evidence[5] that the ferrous state of iron is stabilized by the fluoride.

The nature of both the aluminum and iron salts formed in FNA without HF is such that a tenacious, impervious coating is not produced on the metal surface, and thus uniform passivation due to the formation of these salts is not observed. With aluminum, due to the relatively low solubility of the aluminum salt, a coating appears on the metal with corrosion, and a corresponding retardation in over-all corrosion rate is noted with time. However, the metal is susceptible to localized attack since the aluminum compound is not tenacious or impermeable. In the case of iron alloys with low alloy content, due to the very high solubility of the iron salt, corrosion is likely to be excessive.

The concentration of dissolved aluminum in the presence of various concentrations of fluoride at 25 C is shown in Figure 2. These data were obtained by adding successive amounts of HF to a liquid-phase of fuming nitric acid saturated with respect to aluminum corrosion product at 25 C. Also included in this figure is a solubility measurement made at 25 C on Baker and Adamson's reagent-grade aluminum fluoride.[4] In Table 2 and Figure 3 the solubility of this Baker and Adamson's reagent-grade aluminum fluoride is shown as a function of temperture. The interesting behavior upon adding HF to acid saturated with Al (see Figure 2) is that the aluminum concentration decreases rapidly from 0.075 wt percent to about 0.01 (at 0.15 wt percent F) and then rises to a constant value of about 0.03 wt percent (at 1.0 wt percent F and greater). This reproducible behavior has not been explained although it may be due to variation in composition of the solid-phase, depending on the amount of HF present. It is noteworthy in connection with passivation that the presence of HF markedly reduces the solubility of aluminum (see Figure 2). Under the conditions of the experiments the precipitate formed was composed of very fine particles, whereas the aluminum nitrate formed in the absence of HF was composed of large crystals. The role of the physical structure of the precipitates in leading to passivation needs to be studied. The large aluminum nitrate crystals formed in the FNA that does not contain HF also can present problems in propellant handling by clogging filters used in acid transfer equipment. Such crystals are likely to form when manufactured FNA without HF has been stored in aluminum containers for periods of weeks.

The atomic ratio of fluorine to aluminum found in the liquid-phase fuming nitric acid saturated with respect to the aluminum-fluoride compound is about 6 in the temperature range 0 to 55 C (see Table 3). This atomic ratio suggests that some complex such as $AlF_6^{\equiv}$ is present in solution.

Iron compounds. The concentration of iron in equilibrium with the solid phase formed *in situ* by corrosion of pure iron in fuming nitric acid is shown in Figure 1 and Table 1. It is seen that for this solid compound to be in equilibrium with the solution, 2 wt percent of Fe must be in solution. Such a concentration represents a large extent of corrosion of metal for storage conditions where a large volume of liquid-to-metal surface ratio exists. Also, from visual observation it was found that the precipitate consists of large crystals which are not conducive to the formation of a tenacious, adherent protective coating on the metal.

The solubility of the less soluble iron-fluoride compound is shown in Figure 3 and in Table 2. The compound was prepared by adding HF to FNA, saturated with respect to iron. The wet precipitate was separated from the solution and allowed to saturate a fresh sample of fuming nitric acid. The solid phase in equilibrium was analyzed for iron and fluorine, and the resulting analysis showed the compound to have a fluorine-to-iron atomic ratio of 4 to 1, suggesting the existence of a complex fluoride of iron in solution as was found for aluminum. In Figure 4 is shown the effect of adding various amounts of HF to FNA liquid phase saturated with the iron fluoride compound. It is seen that the solubility of iron fluoride decreases continuously with the fluoride content of the FNA and reaches a minimum value of about 0.013 wt percent at 0.5 wt percent F in solution.

Chromium and nickel compounds. The concentration of chromium and nickel, respectively, in FNA in contact with samples of the fluorides (NiF_2, Baker and Adamson's technical grade, and $CrF_2 \cdot 9H_2O$, Fisher's reagent grade[5]) is shown in Figure 3 and Table 2.

The solution in contact with these fluorides is found to have a high atomic ratio of fluorine to metal as shown in Table 3, suggesting again the presence of complexes between the metal and fluoride.

Corrosion Measurements

Previous measurements[1,2,3] showing the possible relationship between insoluble fluoride compounds formed on the surface of a metal and the inhibition of the corrosion processes of steel and aluminum alloys in FNA have been made. The following analytical and solubility

[4] Manufactured by Baker and Adamson Company, Allied Chemical and Dye Corp., New York, New York.

[5] Manufactured by Fisher Scientific Company, Pittsburgh, Pa.

TABLE 2—Concentration of Various Metallic Ions and Fluoride in Fuming Nitric Acid Saturated with Corresponding Metal-Fluoride Compound

Temperature (Degrees C)	Amount of Constituent in Solution at Equilibrium (Wt. Percent)							
	Aluminum-Fluoride		Iron-Fluoride[a]		Chromium-Fluoride		Nickel-Fluoride	
	Al	F	Fe	F	Cr	F	Ni	F
0	0.010	0.044	0.092	0.130	0.006	0.025	0.11	2.1
15	0.011	0.046	0.093	0.130	0.023	0.060	0.14	2.0
30	0.012	0.048	0.095	0.130	0.051	0.087	0.16	1.8
45	0.013	0.050	0.096	0.131	0.045	0.074	0.19	1.3
55	0.014	0.052	....	....	....	....	....	....

[a] Prepared in the laboratory; all other compounds are commercially available.

TABLE 3—Atomic Ratio of Fluorine to Metal in Solution in Fuming Nitric Acid Saturated with Metal-Fluoride Compound from 0 to 55 C

Compound	Fluorine/Metal Atomic Ratio
Al-F	6 to 1
Fe-F	4 to 1
Cr-F	5/1 to 11/1
Ni-F	21/1 to 60/1

data were obtained to determine the over-all chemical composition of the passivating fluoride coatings.

Aluminum alloys. From measurements of corrosion of Al 6061-T6 at 130 F, the solubility mechanism has been indirectly tested. The coating on the surface of aluminum subjected to samples of fuming nitric acid containing from 0.1 to 1 wt percent HF has been removed by an eraser, analyzed, and found apparently to have the general formula: $AlF_3 \cdot Al_2O_3$. In one corrosion test at 130 F made on a tube whose resistance was measured with time to determine the extent of corrosion with time, it was found that the rate of corrosion decreased steadily with time and finally approached zero after two weeks. Analyses of these equilibrium solutions have an aluminum-to-fluorine ratio of 4 to 6.

As seen in Figure 5, with increase in HF above about 0.4 wt percent, an increase in corrosion rate is observed in the case of aluminum, making it a good practice to keep the HF concentration near this value in inhibited FNA. Also the corrosion of a fresh aluminum surface is found to be greatly reduced in a solution saturated with the passivating compound. This fact together with the similarity between the shape of the solubility curve in Figure 2 and the corrosion curve of Figure 5 suggests further that solubility plays a significant role in the inhibition process.

Iron alloys. From corrosion studies with iron alloys 4130 (1 percent Cr), 410 (12 percent Cr), and 347 (18 percent Cr, 8 percent Ni), the solubility mechanism of passivation by HF has been further tested. From an analysis of the coating on these alloys, it appears that the main constituent is an iron fluoride admixed with FeO or Fe_3O_4. In addition, with alloy 4130 about 2 wt percent of Cr, probably as CrF_3, is found in the coating. With alloy 410 about 3 percent Cr is found, and in 347, 20 percent Cr and 8 percent Ni are found. That Cr and Ni fluorides play a role in the passivation process is borne out by the fact that the ease of passivation increases with an increase in alloy content. Passivation of iron alloys containing no Cr or Ni such as C1020 steel is more marginal and is very sensitive to environmental conditions.[3,4]

If the FNA solution is initially saturated with respect to compounds comprising the coating on an iron alloy such as 347, the total extent of corrosion of a fresh sample to produce passivation is greatly reduced. With steel 347 the corrosion rate decreases continuously with an increase in HF from 0 to 0.8 percent HF, and then increases very slightly with increase in HF as shown in Figure 5. Again the similarity between the solubility curve of Figure 4 and the corrosion curve of Figure 5 suggests that a solubility mechanism probably is involved in the passivation process.

Diffusion Measurements

The effects of diffusion on the passivation process for the case of uni-

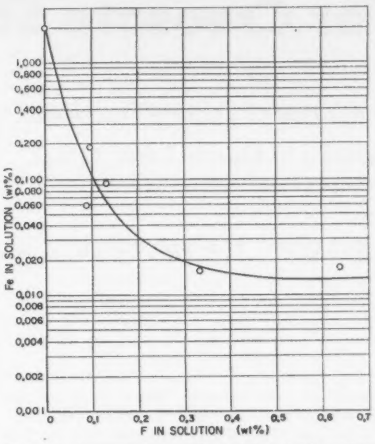

Figure 4—Concentration of Fe and F in fuming nitric acid saturated with solid aluminum-fluoride compound at 25 C.

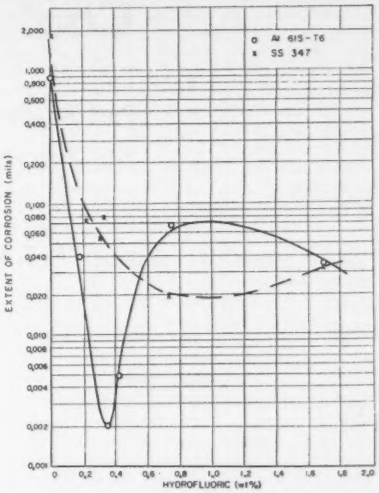

Figure 5—Effect of HF concentration on extent of corrosion of Al 61S-T6 and steel 347 at 130 F for 15 days.

dimensional diffusion were briefly studied by measuring the concentration of metal dissolved at a given time as a function of distance from the metal surface. A disc of metal was placed snugly against a circumferential shoulder near one end of a Teflon tube of ¼-inch inner diameter, and both ends were equipped with tapered Teflon plugs. The tubes were kept pressure-tight by inserting them in a rack and putting both plugs under compression. Each of the tubes, completely filled with fuming nitric acid, was immersed in a horizontal position in a constant-temperature bath. After one week, the tube with its contents was carefully removed from the bath and immersed in liquid nitrogen, keeping the tube horizontal throughout. The tube and its frozen contents were then broken into sections at scribe marks made at definite distances from the metal disc, and the dissolved metal within each section was determined analytically.

In these experiments, it was found that the passivation process markedly decreases the apparent rate of diffusion. In one case where HF was not present, Al was found well distributed throughout the six-inch-long tube after one week at 130 F. In the corresponding case with HF, where passivation occurs, the dissolved aluminum was found in measurable amounts only at a distance of one inch from the metal disc. That the passivating coating can cause local retardation in the rate of corrosion and therefore reduce the distance of diffusion of metallic ions suggests that for short periods of time it is not necessary for the solution to be saturated for effective retardation of corrosion rate. However, of course, to ensure permanent passivation over long periods of time the solution must be completely saturated with aluminum fluorides. The actual quantitative aspects of the role diffusion may play in slowing down the corrosion rate were not defined by this experiment and should be further investigated.

Conclusions

As a result of these studies, passivation of the corrosion of metals by HF in fuming nitric acid by a solubility mechanism has been indicated. It has been shown that to minimize the extent of corrosion before passivation, both the dissolved metal species as well as fluoride should be present in the fuming nitric acid. The detailed steps in the mechanism of the passivation process remain to be systematically investigated. The apparent chemical formulas of the passivating coatings removed from the metal surfaces have been determined. Their precise structure and physical nature should be established by X-ray diffraction, grain size, and film thickness measurements in order to give fundamental information for a better understanding of passivation. The role diffusion or adsorption plays on the long-term effectiveness of the passivation, particularly in the case of low alloy steels, should be studied in more detail.

Acknowledgment

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Coal Tar Creosote Studies*

Part 2—An Evaluation of Certain Fractions For Their Resistance to Marine Borer Attack

By T. R. SWEENEY,(1) T. R. PRICE(1) and S. M. MILLER(2)

Abstract

A study was made of the effect of certain creosote fractions in preventing attack of wood by marine borers. Pine panels used in tests were impregnated with creosote over a range of 5 to 20 pounds per cubic foot and with fraction equivalents of 10 to 15 pounds per cubic foot. Tests were made to determine both initial borer resistance and long-term protective ability of cresote fractions. Data given include the relative performance rating compared to whole creosote of base-free creosote, acid-free creosote acid-and base-free creosote, solids-free creosote, tar-free creosote, petroleum ether-soluble creosote, distillation-residue-depleted creosote, distillation residue, acid-free petroleum-ether-soluble-creosote, and six distillation-fraction-depleted creosotes. 3.3.3

Introduction

WOODEN STRUCTURES, continuously or intermittently submerged in coastal waters, are subject to attack by certain crustacea and molluscacommonly referred to collectively as marine borers. These pests have plagued man since antiquity, and the cost of their depredations runs into millions of dollars annually. Although ecological and physiological studies on marine borers subsequently may point the way to a more subtle method for their control, the two methods in general use today are armoring of the wood and impregnation of the wood with preservatives. The most widely used preservatives are coal tar creosote and solutions of creosote and coal tar.

The creosote in general use by the wood-preserving industry today is a distillate of the tar produced from the high-temperature carbonization of bituminous coal with a distillation range of approximately 200-400 C. It is a complex mixture of hydrocarbons, phenols, amines, and other classes of compounds containing sulfur and nonacidic oxygen. Why this complex mixture of chemical compounds known as creosote should function effectively as a preservative and which constituent class of compounds or individuals make major contributions to its effectiveness is still obscure. Ramage and Burd[1] found that 2 inch x 4 inch x 18 inch panels which had been treated with creosote freed of low boiling tar acids (phenols) stood up well when exposed to marine borer attack.

Creosote containing high percentages of light oils or tar acids were found by MacLean[2] to be less effective than whole creosote. He also found that the higher boiling creosotes and creosote fractions were among the most effective tested.

Becker and Schulze[3] impregnated 5 cm x 2.5 cm x 1.5 cm pine blocks with creosote fractions of various boiling ranges and, after an elaborate weathering of the treated blocks, hung them individually in small aquaria containing sea water. A number of *Limnoria* were then introduced and from the number of surviving animals and the degree of attack on the panels the efficacy of the various fractions was determined. These workers found that fractions boiling up to 240 C were ineffective. Among the higher boiling constituents those within the boiling range 200-300 C were most effective and those within the range 300-330 C least effective.

The present communication contains the results of an evaluation of several creosote fractions for their ability to resist marine borer attack.

Preparation of Materials

Creosote

The creosote used in this investigation was taken from a large stock reserved for present and future Navy research. It is a medium residue creosote and meets the AWPA Standard P1-54.

Creosote Fractionation

Removal of tar acids: One hundred grams of creosote were dissolved in 150 ml of benzene and the solution extracted with four successive portions of Claisen alkali. The Claisen alkali was prepared by dissolving 350 gm of potassium hydroxide in 250 ml of water and bringing the total volume to 1000 ml with methanol. After extraction the residual benzene solution was washed well with water and the solvent removed by distillation. The quantity of tar acids removed from creosote by extraction with Claisen alkali has been shown to be twice that that can be removed by extraction with aqueous alkali.[4]

Removal of tar bases: A solution of creosote in benzene as described above was extracted successively with four 100 ml portions of 10 percent hydrochloric acid. The residual solution was washed with water until free of acid and the solvent removed by distillation.

Removal of tar acids and tar bases: The tar acids were removed from the creosote first as described above. The residual benzene solution was then treated with hydrochloric acid as described for the removal of the tar bases.

Treatment with petroleum ether: One-third volume of petroleum ether (boiling point 30 to 60 C) was slowly added with stirring to creosote and the precipitated solid was removed by filtration. The solvent was removed from the filtrate by distillation to yield what in this paper is termed "solids-free creosote." To obtain the so-called "petroleum ether soluble fraction" additional petroleum ether was added to the filtrate from the above filtration and the solution allowed to stand overnight. The clear, light yellow, supernatant liquid was then decanted from the precipitated tar and the solvent removed by distillation. The product is an amber fluid, much less viscous than creosote, and leaves wood with a clean, attractive appearance after impregnation. To obtain the so-called "tar-free creosote" the precipitated solids were added to the petroleum ether-soluble creosote.

Distillation: Creosote was distilled through a saddle-packed heated column, 25 cm long and 1.8 cm inside diameter, fitted with a heated total reflux head and fraction collector. For a distillation the stillpot was charged with about 1500 gm of creosote. It was found highly desirable to seal the column to the stillpot for distillations under reduced pressure. Small leaks, which developed when ground glass joints were used, caused excessive sublimation. A summary of the distillation results is given in Table 1. A summary of the creosote fractions and their percentage in whole creosote is given in Table 2.

Preparation of panels: Clear, edge grain, sapwood (benzidine test) southern pine panels, 5 x 1½ x ⅛ inches, were used for this study. Panels were dried to constant weight at 105 C before impregnation. Weight tolerances were established at 8.25 ± 0.75 gm. Panels were impregnated by submerging them in the creosote or fraction held at 80 C in an ordinary hydrogenation bomb and applying the desired pressure by the admission of nitrogen. After impregnation the panels were allowed to bleed to constant weight in a desiccator.

Panel Exposure and Evaluation

The method for evaluating creosote fractions which is described in the follow paragraphs is a precursor of the one currently in use and which is described in detail elsewhere.[5]

Panels were prepared and exposed in four groups of six sets each. Each group contained duplicate sets of panels prepared from whole creosote and dup-

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(1) U. S. Naval Research Laboratory, Organic and Biological Chemistry Branch, Washington, D. C.

(2) Marine Laboratory, University of Miami, Coral Gables, Florida.

licate sets for each of two creosote fractions. Each whole creosote set consisted of 60 panels which were impregnated over a range of 5 to 20 pcf (pounds per cubic foot). Each fraction set consisted of 20 panels impregnated over a range of fraction equivalent to a range of 10 to 15 pcf of whole creosote. This was done because it was deemed desirable to compare a fraction with its equivalent weight of whole creosote rather than an equal weight. An attempt was made to vary the degree of impregnation evenly over the selected ranges.

Two procedures were used in the evaluation of each creosote fraction. One, to determine the initial borer resistance of a fraction relative to whole creosote, consisted of exposing a fraction-treated and a creosote-treated set of panels simultaneously to marine borer attack for a given time and measuring the damage sustained by each. The other procedure was similar except that before exposure the sets were subjected to leaching in hot water (80 C) for 16 days. The latter treatment was an attempt to assess the permanence, or long-term protective ability, of a fraction in a reasonable length of time without having the leaching or weathering complicated by the superimposition of marine borer attack.

The leaching was accomplished in a 55-gallon stainless steel, heated tank which could accommodate about 200 panels. The tank was equipped at each end with thermo-regulators which were capable of maintaining a continuous stream of fresh water at the desired temperature. The leached and unleached sets of panels were exposed in the sea simultaneously. During exposure the panels were scraped free of fouling biweekly and inspected and rated bimonthly. When all of the panels in a whole creosote set had sustained an attack of at least 1, that set along with its corresponding fraction sets was removed from exposure.

Creosote fractions were evaluated on the basis of their ability to impart to the wooden panels a resistance to marine borer attack. Damage, measured on a scale from 0 (no attack) to 5 (very heavy attack), was related to the actual number of borings and was expressed numerically as the sum of the *Limnoria* attack (L) plus twice the *Teredo* attack (T), i.e., $L + 2T$. The *Teredo* attack was doubled in order to compensate for the large surface-to-volume ratio of the panels. Because of the yearly and seasonal fluctuation in marine borer activity in the exposure area, absolute measurements of attack are impossible and hence all attack ratings ($L + 2T$) are converted to a performance rating relative to whole creosote.

Attack ratings on individual panels for any set were converted to a performance rating for the set as follows. It was first established that, over the range of impregnation investigated, it was sufficiently accurate to express attack as a linear function of retention. On this basis, the constants m (slope) and b (intercept) of the equation $y = mx + b$, expressing a linear relationship between the intensity of marine borer attack, y, and the concentration of preservative in the panels, x, were calculated by the method of least squares from the data for each set of panels. The intensity of attack, as mentioned previously, is expressed as $L + 2T$; concentration of preservative is expressed in terms of whole creosote equivalent to the actual quantity of fraction impregnated. Because the damage at the midpoint of the retention range studied (12.5 pcf) is proportional to the area under the curve, the performances of fractions and whole creosote were compared at this point. The attack rating for a fraction at this point was calculated from the appropriate derived equation and this rating was then converted to a performance rating through the expression:

$$\frac{\text{attack on whole creosote}}{\text{attack on fraction}} \times 100 = \text{performance rating.}$$

In addition to a performance rating on each fraction, a permanence rating was obtained through the expression:

$$\frac{\text{performance rating (leached)}}{\text{performance rating (unleached)}} \times 100 = \text{permanence rating.}$$

The permanence rating indicates nothing of the extent of attack but does indicate how well a fraction stands up to the deleterious effect of leaching relative to whole creosote.

Impregnation with the distillation residue posed a special problem and emphasized the need to abandon the practice of impregnating panels with creosote fractions on the creosote equivalent basis. With fractions that constitute a large percentage of whole creosote it is not difficult to obtain a range of impregnations equivalent to 10 to 15 pcf of whole creosote; with small fractions, however, the difficulties are considerable. For example, a fraction consisting of 10 percent of whole creosote would have a range of 1 to 1.5 pcf equivalent to 10 to 15 pcf of whole creosote. This would amount to no range at all for practical exposure work. For this reason panels were impregnated with the distillation residue on a pound for pound basis; that is, at an actual level of 10 to 15 pcf and not its equivalent in whole creosote. To obtain the rating of the distillation residue, therefore, the ratio of the attack at 12.5 pcf of creosote to the attack at 4.4 pcf of residue (12.5 pcf creosote equivalent) was determined from the appropriate equations. The attack at 4.4 pcf of residue is, of course, a value obtained by extrapolation. The performance and permanence ratings for the various fractions are shown in Table 2.

TABLE 1—Summary of Creosote Distillation

Fraction	Temperature (Degrees C)	Pressure (mm Hg)
	<200	760
	200–235	760
	235–130	760–15
	130–160	15
	160–190	15
	190–210	15
Residue	>210	15

Discussion of Results

Because of the large variation inherent in biological measurements a small difference in the performance rating of a fraction relative to creosote is probably of little significance. However, some results stand out in Table 2.

The removal of the tar acids gives a superior product. This was also indicated in earlier experiments (not reported) and supports the finding of MacLean that the fortification of creosote with tar acids gave an inferior product. Even after leaching the tar-acid-free creosote appears to be as good as whole creosote. The low permanence rating is a reflection of the excellent performance of the unleached material. The beneficial effect of removing tar acids also is exhibited in the performance of the petroleum ether soluble fraction with acids removed.

The removal of the tar bases and both tar bases and acids gave products that performed somewhat better than creosote before leaching. However, like the acid-free creosote, they did not hold up to leaching very well and the poor permanence rating of these fractions may indicate that the tar acids and bases contribute, in some way, to the ability of creosote to resist leaching from wood.

The petroleum ether soluble fraction of creosote performed somewhat better than whole creosote, especially after leaching. This creditable performance coupled with its ease of handling and its ability to leave wood clean and attractive after impregnation may have commercial significance.

It can be seen from Table 2 that creosote with the distillation residue removed gave a poor performance. However, since the residue alone also gave a poor performance, it is not likely that removing residue from creosote removed any highly toxic material but rather de-

TABLE 2—Comparison of the Performances of the Various Creosote Fractions

FRACTION	Percent of Whole Creosote	RATING*		
		Performance		
		Not Leached	Leached	Permanence
Whole creosote	100	100	100	100
Base-free creosote	96.5	141	74	53
Acid-free creosote	94.4	300	95	32
Acid-and base-free creosote	91.9	140	103	74
Solids-free creosote	92.6	121	136	112
Tar-free creosote	91.1	91	117	129
Petroleum ether-soluble creosote	83.7	117	141	121
Distillation-fraction-2-depleted creosote	80.1	85	68	81
Distillation-fraction-3-depleted creosote	93.2	167	100	60
Distillation-fraction-4-depleted creosote	92.7	105	84	81
Distillation-fraction-5-depleted creosote	91.8	90	88	98
Distillation-fraction-6-depleted creosote	84.5	63	60	95
Distillation-residue-depleted creosote	64.8	33	20	60
Distillation residue	35.2	28	66	235
Petroleum-ether-soluble-creosote, acid free	79.4	130	103	80

* Relative to whole creosote taken as 100.

creased the ability of the creosote to remain in the wood. This view is supported by the very high permanence rating of the distillation residue.

Distillation fraction 6 also seems to make a distinct contribution to the effectiveness of creosote as is seen by the inferior performance of the distillation-fraction-6-depleted creosote. The removal of distillation fraction 3 from creosote yields a product which is apparently superior to creosote. This is surprising and unexpected and no explanation is offered at the present time.

On the basis of the pattern of the leaching of whole creosote from wood[5], which of course may not be exactly comparable to that for the fraction-depleted creosotes, leached panels would be expected to have lost all of distillation fractions 2 and 3, most of 4, and an appreciable percentage of 5, 6, and distillation residue. This would mean that, in the case of the leached panels, only distillation fractions 5, 6, residue, and to a lesser extent, fraction 4, could be present to furnish protection. With a creosote depleted of one of these fractions by distillation, the remaining ones would be responsible for any protection. Since the residue alone offers a rather low order of protection to unleached wood but, on the other hand, is necessary to the efficient action of whole creosote as shown by the poor performance of residue-depleted creosote (Table 2), there is a strong indication that distillation fractions 4, 5, and 6 may be providing a large measure of the toxicity and that the residue (and to some extent fraction 6) may be providing the means of holding these fractions in the wood. Additional experiments on panels impregnated with the individual distillation fractions also have indicated that fractions 5 and 6 make the largest contribution to the protective action afforded by creosote. It is hoped that these results can be reported in detail in the near future.

Because, as mentioned, distillation fractions 2 and 3 would be expected to be completely removed from the wooden panels by the leaching process, it might be anticipated that panel sets impregnated with whole creosote, distillation fraction-2-depleted, or distillation fraction-3-depleted creosotes would all exhibit similar resistance to marine borer attack after leaching. That this was not the case with fraction-2-depleted creosote may be a reflection of the limitations of the bioassay procedure or may be due to the possibility that fraction-2-depleted creosote does not respond to leaching in a manner similar to whole creosote.

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Any discussions of this article not published above will appear in the December, 1958 issue

Minimum Current Requirement Solution Is Elusive

Differing Views Are Weighed Again By T-2C Unit

Intensive and lengthy discussions of major problem facing Technical Unit Committee T-2C on Minimum Current Requirements (Pipe Line Corrosion), is reflected in a report of the committee meeting held in San Francisco March 17, 1958.

Principal problem of the committee is to prepare a statement as to what constitutes minimum requirements for the protection of buried pipe lines. Chairman Ray M. Wainwright, Good-All Electric Mfg. Co. explained that in response to a request for written reports, on this subject, three proposals had been received.

Following the reading of the reports by Mr. Wainright, a variety of problems on the subject of stating minimum current requirements was discussed by several present. Questions concerning coated pipe, bare pipe and the problem of whether "immediate proximity" should be interpreted electrically or otherwise in the placing of a measuring cell to obtain criteria were brought up. Many other points were considered.

Statement Is Needed

One person present inquired whether the statement of criteria on minimum requirements would be for the benefit of the corrosion engineer or for benefit of management. It was pointed out that such a statement would represent the combined thinking of a group of people who daily are faced with the problem; it would help the corrosion engineer and would give management some idea of what might reasonably be expected of the corrosion engineer. Chairman Wainwright pointed out that such a statement on cathodic protection is very much needed to avoid the possibility some other and possibly less qualified persons undertake to set up false criteria and broadcast erroneous statements on the subject.

Duties of the various task groups and status of their work were explained by the chairman at the beginning of the meeting. A nominating committee was appointed to select candidates for committee offices. A special commitee was appointed to consider the various proposals received by the Committee T-6B and formulate them into a statement to be submitted to membership for approval.

Committees Appointed

Members appointed to the nominating committee are L. P. Sudrabin, Electro Rust-Proofing Corp.; A. F. Minor, American Telephone & Telegraph Co.; W. H. Stewart, Sun Pipe Line Co., and R. M. Wainwright.

The special committee included the following: L. P. Sudrabin, R. M. Wainwright, L. C. Wasson, A. O. Smith Corp.; W. H. Bruckner, University of Illinois; Marshall Parker, consulting engineer; L. B. Nelson, Shell Pipe Line Co. and A. W. Peabody, Ebasco Services, Inc.

As a detailed report of work done by Task Group T-2C-2 on Coupons as a Criteria for Cathodic Protection, was presented by Harry J. Keeling, consulting engineer. Samples of coupons used to test effectiveness of corrosion preventive measures were shown. W. M. Schilling, Southern Counties Gas Co. had assembled data on more than 5000 coups used by his firm. Several points concerning the report, especially the drawbacks of the method were discussed by Mr. Schilling and others.

Corrosion Cost Data Are Reviewed by T-3C

Unit Committee T-3C on Annual Losses Due to Corrosion heard a review of kinds of cost data available from previous workers in the field, followed by a general discussion of ways and means for securing reliable cost information and utilizing it to make management aware of the destructive effects of corrosion. The committee met in San Francisco in March.

S. K. Coburn, Association of American Railroads, chairman, described briefly the purpose of the committee. He then gave a brief summary of the cost data available through the work of H. H. Uhlig, work of the American Petroleum Institute Tanker Committee with a report by Watkins, the API refinery losses described at nine cents a barrel and more recently the work of a subcommittee which prepared a preliminary report for the Northeast Region meeting in Pittsburgh, 1957.

Mr. Coburn said he believes a report on industrial purchases of corrosion resistant materials represents the best information available. The survey was carried out by staff members of a large industrial firm capable of conducting a market survey. Results were extrapolated to indicate national costs.

Waterflood Corrosion Task Group Being Formed Now

A subcommittee on waterflood corrosion is being formed under Group Committee T-1 on Corrosion in Oil and Gas Well Equipment. H. E. Greenwell has been appointed temporary chairman to hold an organizational meeting. Those interested in becoming members should write to H. E. Greenwell, Production Profits, Inc., 8912 Sovereign Row, Dallas, Texas.

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Maps of the miles of metal pipe, power and communication cables underground in large metropolitan areas are being mapped by committees affiliated with NACE's T-7 committee.

Revision of Two Pipe Coating Reports Made By T-2H Committee

A brief summary of important past accomplishments and future plans for committee activity occupied members of Unit Committee T-2H on Asphalt Type Pipe Coatings meeting in San Francisco, March 19, during the NACE 14th Annual Conference.

Two interim committee reports were published in the April and May 1957 issues of Corrosion. The first interim report, Tentative Recommended Specifications for Asphalt Type Protective Coatings for Underground Pipe Lines—Wrapped Systems was discussed for revision and future publication but no action was taken. It was carried over as future business for the committee.

Revision of specifications contained in another report, Statement on Minimum Requirements for Protection of Buried Pipe Lines published in October 1956 were reported on at the 13th Annual Conference, St. Louis in 1957. Members, voting by letter ballot after the 1957 meeting, approved the revised specifications. These approved revisions were considered at the San Francisco meeting and minor amendments were made.

Members of Task Group T-2H-4 reported to the committee the group's conclusion that a minimum of three separate specifications would be required for the most effective coverage of "Internal Pipe Treatment Specifications." The specifications are: a) Asphalt Protective Coatings for Culvert Pipe. b) Asphalt Protective Coatings for Portable Water Pipe. (Dip Method). c) Asphalt Protective Coatings for Pipe Lines—Coatings for Interior Surfaces, Centrifugally Cast.

There is a possibility a new task group will be formed to compile information on asphalt testing techniques on a non-technical level. A member suggested information be assembled on test techniques, screening and sampling methods, with a non-technical explanation of tests and techniques.

Cincinnati Meeting Is Planned by HF Unit

A meeting of Task Group T-5A-6 on HF Corrosion is being planned for Cincinnati, Ohio, October 15-17. The group has two surveys under way, one on HF alkalation corrosion and another on suitable alloys for use by HF manufacturers. In addition, the problem involving HNO-HF in uranium ore recovery is being investigated.

A report that HF is being favored as a mineral acid in chemical processing was made at the group's meeting last March 17 in San Francisco. This meeting was held during the 14th Annual Conference. Next October's session will be during the North Central Region meeting.

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SUBSIDIARY OF PARKER RUST PROOF COMPANY

Fruitful Meeting of Protective Coatings Committee Held at 14th Conference

Is Hydrogen Sulfide "Friend or Foe"?

A discussion on whether hydrogen sulfide is "friend or foe" of the corrosion engineer, a decision to deactivate a task group and discussion on where to hold committee meetings were main features of the meeting of Unit Committee T-1D on Sour Oil Well Corrosion. The meeting was held in San Francisco, March 19, 1958.

On the subject of hydrogen sulfide, it was pointed out that a technical paper presented at the meeting had said that in some instances hydrogen sulfide acts as an inhibitor. However, a member said he thought hydrogen sulfide always made corrosion worse, giving an instance of corrosion in tubing to support his position. Other factors, such as presence of oxygen and of carbon dioxide with hydrogen sulfide were brought up.

It was decided to deactivate Task Group T-1D-1 on Fundamentals of Corrosion after Chairman John Sudbury said that participation was very limited. The committee decided that the group chairman should continue to promote interest in the subject and could present any reports he can get to the committee.

New officers of T-1D are Parke D. Muir, chairman and Jack Collins, vice-chairman, who took over at the end of the San Francisco meeting.

The suggestion was made that the committee meet only once a year and that this meeting be held in conjunction with the South Central Region meeting. In discussion, it was pointed out that some members are far removed from the South Central Region.

Comments by Production Men Sought on Plastics

The suggestion has been made that Unit Committee T-1J on Oil Field Structural Plastics ask oil production men to comment on the uses for plastics in the oil fields and to define corrosion conditions in which reinforced plastics can be used effectively. The suggestion was made to strengthen the committee, particularly to encourage action by those who use plastics, or encounter corrosion problems where plastics can help.

Possibility of coordinating T-1J with T-5D on Plastic Materials of Construction was also considered on the premise the combination would be sufficient to handle the problems of both chemical and oil industries. It was recommended this be considered by both groups.

An indication of need for T-1J, according to a spokesman, will be whether or not users of plastics will attend the meeting of the committee in New Orleans in October. Only an informal meeting was held in San Francisco.

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The exhibition scheduled to be held at New Orleans October 21-23 during the South Central Region's Conference at the Roosevelt Hotel will be the third held by the region.

An offer of the use of private company test racks, a suggested method of preparing and presenting reports and a list of 20 subjects on which data are needed are contained in the report of activities by Technical Unit Committee T-6B on Protective Coatings for Resistance to Atmospheric Corrosion. The subjects were discussed at a session held in San Francisco, March 19.

Thirteen guests attending expressed an interest in becoming members of the committee. It was suggested that these guests be contacted by chairmen of the various groups in T-6B. Purpose of T-6B was explained to all present by reading the concise, written scope of the committee.

Reports Standardized

It was decided that information obtained through efforts of members working together would be made available by preparation and presentation of reports. Format and method of preparing the reports would be similar to that already established by Unit Committee T-6A on Organic Coatings and Linings for Resistance to Chemical Corrosion.

Offer to T-6B or any of its task groups of the use of test racks in Arabia was made by William F. Gross of Arabian American Oil Co. Harry Alderson of Pacific Gas and Electric Co., also offered use of his firm's test racks on the California coast at Eureka, pending permission by the company.

Task Group Changes

Among some of the task group personnel changes discussed were: T-6B-1, where Joseph Bigos resigned as chairman; T-6B-5 and T-6B-6 found it necessary to select new chairman because of the retirement of G. G. Sward. J. I. Richardson, Amercoat Corp., accepted the chairmanship of T-6B-10. Present chairmen of task groups T-6B-12, T-6B-13 and T-6B-14 will stay on. Task Group T-6B-15 on Silicones was formed and W. F. Gross accepted the chairmanship.

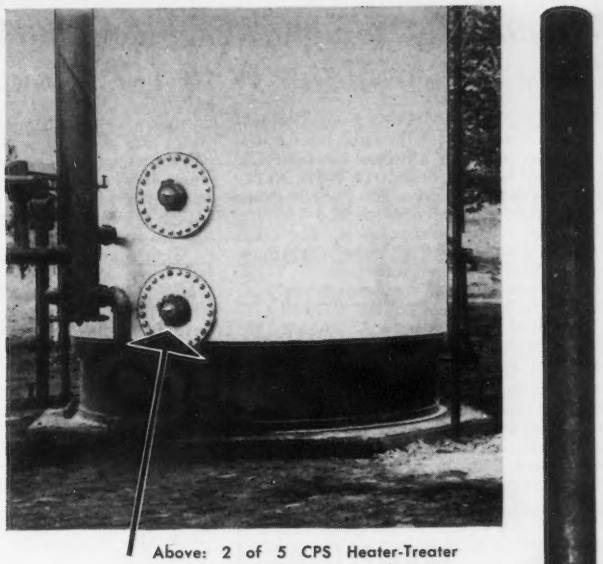
The suggestion was made that all task groups include 20 subjects in their work. These are: Surface preparation, number of coats, film thickness in mils, drying time, application, temperature limitations during application, thinners, flammability, compatibility, abrasion, gloss retention, petroleum oil resistance, maximum temperature limitation, storage life, precautions, atmospheric chemical resistance, a) caustic, b) acid, c) other; formulation differences, type of attack, service life and decorative value.

Next meeting of the committee was planned for October, 1958.

T-6J Meets in June

Technical Unit Committee T-6J, Los Angeles Area, Protective Coating Application Problems scheduled a program conducted by John Richardson, Amercoat Corp. for June 18 meeting in Rodger Young Auditorium. T-6J has adopted a policy of presenting at meetings, topics pertinent to application of protective coatings and the various problems met in this work. The committee meets frequently. Also scheduled for the June meeting was a reading of minutes of other T-6 Committees from the San Francisco Conference last March.

TRICKS... for... TREATERS



Above: 2 of 5 CPS Heater-Treater Anodes installed in a vertical treater.

Oilfield emulsion treaters and related equipment . . . handling corrosive brines . . . can well use a few *tricks* . . . to prolong their woefully short life in such service.

CPS has developed, over the past five years, a complete line of cathodic protection materials . . . rectifiers, graphite and magnesium anodes, deck mounts, control boxes, plus other items for use on this specific corrosion problem.

Standard designs have been worked out for the more widely used models of oilfield vessels, in cooperation with the manufacturers.

For complete information, please call or write your nearest CPS office, or consult with your tank company representative.

Vertical mounting fittings for magnesium and graphite suspension.

Right: Heater-Treater magnesium (30") and graphite (60") anodes assembled ready for horizontal mounting. Both lengths available in magnesium or graphite.

Note: Caps are now made of plastic.

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Columbus and Central Ohio Committee on Corrosion Affiliates With T-7 Group

Members of the Columbus and Central Ohio Committee on Corrosion have voted unanimously to affiliate with NACE Technical Group Committee T-7B, North Central Region Corrosion Coordinating Committee. Included with the bid for affiliation was the request by the Ohio group asking how they could contribute information to other members of T-7B. Both requests were forwarded to C. A. Erickson, Jr., The Peoples Natural Gas Co. and to C. L. Mercer, Southwestern Bell Telephone Co., chairman and vice-chairman respectively of T-7.

The Columbus and Central Ohio Committees on Corrosion, according to directories forwarded by them, consists of corrosion men from 21 companies, representing railroads, telephone and telegraph, electric distribution systems, pipe lines and water distributing systems. The directories list the companies which have installations in cities located in 23 counties in the state. Names and addresses of individuals for each company are given.

Chairman of the Central Ohio Comittee is N. R. Patton, district engineer in charge of the distribution facilities for the Columbus and Southern Ohio Electric Co., Columbus, Ohio. He is responsible for corrosion coordination work for his company. He is a graduate electrical engineer from the University of Cincinnati and formerly was underground engineer with the Cincinnati Gas and Electric Co. and the Columbia Engineering Corp. He also was employed for 10 years by the Westinghouse Electric Corp. He is a member of the AIEE and NSPE and is doing work with the Edison Electric Institute, Transmission and Distribution Committee.

Secretary of the committee is C. H. Bope, underground engineer, Columbus and Southern Ohio Electric Co.

Chairman of NACE Regional T-7B is Paul C. Hoy, Dayton Power and Light Co. He also is a member of the local committee of the Columbus and Central Ohio Committee on Corrosion.

Included as a frontispiece in each directory is a sample notification blank used by members to notify representatives of other companies and to invite their consultation before work is done which might affect corrosion of their underground plant.

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North Central Region will hold its 1958 meeting October 15-17 at Cincinnati.

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Fifteen local corrosion control committees have affiliated with NACE's T-7 committee in two years.

TECHNICAL REPORTS

on

CORROSION in UTILITIES

T-4B Cell Corrosion on Lead Cable Sheaths. Third Interim Report of Technical Unit Committee T-4B on Corrosion of Cable Sheaths. Compiled by Task Group T-4B-1 on Corrosion of Lead and Other Metallic Sheaths. Publication No. 56-9. Per Copy $.50.

T-4B-2 Cathodic Protection of Cable Sheaths. Fourth Interim Report of Technical Unit Committee T-4B on Corrosion of Cable Sheaths. Compiled by Task Group T-4B-2 on Cathodic Protection. Publication 56-13. Per Copy $1.00.

T-4B-3 Tests and Surveys for Lead Sheathed Cables in the Utilities Industry. Second Interim Report of Technical Unit Committee T-4B on Corrosion of Cable Sheaths. Publication 54-6. Per Copy $.50.

T-4B-4 Pipe-Type Cable Corrosion Protection Practices in the Utilities Industry. First Interim Report of Technical Unit Committee T-4B on Corrosion of Cable Sheaths, *Corrosion*, Sept. 54 issue. Publication 54-3. Per Copy $1.00.

T-4B-6 Stray Current Electrolysis. Fifth Interim Report of Technical Unit Committee T-4B on Corrosion of Cable Sheaths, prepared by Task Group T-4B-6 on Stray Current Electrolysis. Publication No. 57-1. Per Copy $1.00.

T-4F-1 Progress Report of Task Group T-4F-1 on Water Meter Corrosion. Per Copy $.50.

TP-12 Report on Electrical Grounding Practices. Per Copy $.50.

TP-19 Corrosive Effects of Deicing Salts—A Progress Report by Technical Practices Committee 19. *Corrosion*, January, 1954, issue. NACE members $.50; Non-members $1 per copy.

Remittances must accompany all orders for literature the aggregate cost of which is less than $5. Orders of value greater than $5 will be invoiced if requested. Send orders to National Association of Corrosion Engineers, 1061 M & M Bldg., Houston, Texas. Add 65c per package to the prices given above for Book Post Registry to all addresses outside the United States, Canada and Mexico.

NATIONAL ASSOCIATION OF CORROSION ENGINEERS

1061 M & M Bldg. Houston 2, Texas

TECHNICAL REPORTS

on

MARINE COATINGS

T-1M Suggested Coating Specifications for Hot Application of Coal Tar Enamel for Marine Environment. A Report of NACE Technical Unit Committee T-1M on Corrosion of Oil & Gas Well Producing Equipment in Offshore Installations. Publication No. 57-8. Per Copy $.50.

T-1M Suggested Painting Specifications for Marine Coatings. A Report of NACE Technical Unit Committee T-1M on Corrosion of Oil & Gas Well Producing Equipment in Offshore Installations. Publication No. 57-7. Per Copy $.50.

Remittances must accompany all orders for literature the aggregate cost of which is less than $5. Orders of value greater than $5 will be invoiced if requested. Send orders to National Association of Corrosion Engineers, 1061 M & M Bldg., Houston, Texas. Add 65c per package to the prices given above for Book Post Registry to all addresses outside the United States, Canada and Mexico.

NATIONAL ASSOCIATION OF CORROSION ENGINEERS

1061 M & M Bldg. Houston 2, Texas

San Francisco Committee Elects New Officers

The Joint Committee for the Protection of Underground Structures in the East Bay Cities, which is affiliated with Unit Committee T-7E, Western Region Corrosion Coordinating Committee, elected new officers at its regular annual meeting January 9, 1958.

The following officers were elected to serve during 1958: R. A. Moulthrop, Pacific Gas & Electric Co., 1625 Clay Street, Oakland 12, Cal., chairman; Leslie Paul, East Bay Municipal Utility District, P. O. Box 4616, Oakland 23, Cal., vice-chairman; C. K. Notley, Key System Transit Lines, 3493 Hollis Street, Oakland 8, Cal., secretary-treasurer.

More Discussions Aim of Protective Linings Unit

Calculated efforts are being made by officers to make meetings of Unit Committee T-6F on Protective Interior Linings, Application and Methods, more effective forums for exchange of information on corrosion problems of lining tanks and equipment. Another principal objective of those guiding the committee is to ensure that mailing lists contain only names of those actively interested in work of the committee.

Wallace P. Cathcart, Tank Lining Corp., chairman of the committee stated in a letter to members that future meetings would minimize administrative details and would devote the time to discussion of problems. To revise the mailing lists, a questionnaire was sent to members and visitors at committee meetings, asking them to signify their desire to either remain members, or in the case of visitors, to become members. Failure to return the questionnaire by July 15, will indicate lack of interest.

Marine Borer Group Talks About Laboratory Work

At the first official meeting of Group Committee T-9 on Marine Biological Deterioration, members heard short discussions of work being done in various laboratories in the nation.

A. L. Alexander, R. W. Drisko, Harry Hochman, Sigmund Miller and T. R. Sweeney discussed briefly the work they are doing in the marine biological field at their respective laboratories. Mr. Alexander and Mr. Sweeney are with the Naval Research Laboratory in Washington, D. C.; Mr. Drisko and Mr. Hochman are with the United States Naval Civil Engineering Laboratories, Port Hueneme, Calif. Mr. Miller is associated with the University of Miami, Florida.

Two papers on marine borers submitted by T. P. May, International Nickel Co., Inc., were discussed at a round table session. The papers were: Occurrence of Marine Borers and Associated Fouling Organisms at Wrightsville Beach, North Carolina, Clapp Report No. 10565, October 20, 1957. The other paper was titled Greenheart and Manbarklak Marine Borer Samples, Clapp Report No. 10528, October 1, 1957. R. C. Miller also described marine borer studies which were being conducted in India.

New Orleans Technical Program Is Outlined

Nineteen Firms Take Space in Exhibition

Contracts for exhibition space at the South Central Region Conference are coming in. Nineteen firms will show their wares to corrosion engineers at the meeting in New Orleans, October 20-24, 1958.

Companies which have contracted for exhibition space are:

S. E. Bosely Company
The Carboline Company
Corrosion Rectifying Company
John Doré Company
Dowell, Incorporated
The Duriron Company
Fibercast Company
Odis C. Galloway & Company, Inc.
The F. W. Gartner Company
F. H. Maloney Company
Metallizing Engineering Company, Inc.
Chas. Pfizer & Company, Inc.
Pittsburgh Coke & Chemical Company
The D. E. Stearns Company
Texsteam Corporation
Valdura Division,
American Marietta Company
Visco Products Company
T. D. Williamson, Incorporated

11 Technical Committees Will Meet in New Orleans

Eleven technical committees and task groups have planned sessions during the South Central Region Meeting to be held in New Orleans, October 20-24. Progress on problems the committees are investigating, business reports and plans for further work will be taken up.

NACE Technical Committees which plan to meet are: T-1 on Corrosion in Oil and Gas Well Equipment, T-1B on Condensate Well Corrosion, meeting in conjunction with T-1B-1 on High Pressure Well Completion and Corrosion Mitigation Procedure; T-1C on Sweet Oil Well Corrosion; T-1D on Sour Oil Well Corrosion; T-1F on Metallurgy; T-1H on Oil String Casing Corrosion; T-1J on Oil Field Structural Plastics; T-1K on Inhibitors for Oil and Gas Wells; T-1M on Corrosion of Oil and Gas Well Producing Equipment in Offshore Installations;

T-2D on Standardization of Procedures for Measuring Pipe Coating Leakage Conductance.

T-3D-1 on Electrical Holiday Inspection of Coatings.

T-5C-1 on Corrosion by Cooling Waters, South Central Region;

T-6A on Organic Coatings and Linings for Resistance to Chemical Corrosion; T-6A-17 on Polyurethanes; T-6B on Protective Coatings for Resistance to Atmospheric Corrosion; T-6D on Industrial Maintenance Painting.

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More than 20,000 cards have been issued by the NACE Abstract Punch Card Service.

NATIONAL and REGIONAL MEETINGS and SHORT COURSES

1958

Oct. 5-8—Northeast Region. Somerset Hotel, Boston, Mass.

Oct. 15-17—North Central Region. Cincinnati, Ohio.

Oct. 20-24—South Central Region. New Orleans, Roosevelt Hotel.

Nov. 17-19—Western Region. Los Angeles, Statler Hotel.

1959

March 17-19—15th Annual Conference and 1959 Corrosion Show. Sherman Hotel, Chicago.

Oct. 12-15—South Central Region Meeting, Denver, Col.

Oct. 20-22—North Central Region, Cleveland.

1960

March—16th Annual Conference and 1960 Corrosion Show. Dallas, Texas, Memorial Auditorium.

No dates set—South Central Region Conference, Tulsa, Okla.

Oct. 11-14—Northeast Region Meeting. Huntington, W. Va.

1961

March—17th Annual Conference and 1961 Corrosion Show. Buffalo, N. Y., Hotel Statler.

Oct. 24-27—South Central Region Conference, Houston, Shamrock Hotel.

1962

March—18th Annual Conference and 1962 Corrosion Show. Kansas City, Municipal Auditorium.

October 16-19—South Central Region Conference, San Antonio, Texas.

Advance Program Mailed On San Joaquin Tour

Information concerning the Guided Field Corrosion Tour to be held Sept. 24-25 was planned to be mailed to members of NACE in California, Oklahoma, Texas, Louisiana and Arkansas. The corrosion tour is an activity of NACE San Joaquin Valley Section.

In two planned mailings, members will be given general tour information, registration fee and a form to be used for requesting additional information.

Purpose of the tour is to study and examine corrosion projects pertaining to the petroleum, refining, public utilities and agricultural industries. Equipment and installations have been selected which will offer, in addition to present corrosion information, the opportunity

(Continued on Page 71)

Four 6-Paper Symposia Are Being Arranged

Work on the technical program for the South Central Region Conference, October 20-24 in New Orleans is gaining momentum. Papers for the technical program are coming in and technical committee meetings are being arranged.

The technical program, when complete, will have six papers in each symposium. Present status of the program with papers already committed is as follows:

Oil and Gas Production

J. L. Battle, Humble Oil and Refining Co., chairman; W. C. Koger, Cities Service Oil Co., vice chairman.

Polyurethanes—Plastic with an Oil Field Promise, by B. P. Goodman, Tube-Kote, Inc., Houston. Results of Mixed Rod String Testing, by W. C. Koger, Cities Service Oil Co., Bartlesville, Okla.

Well Completion and Corrosion Control of High Pressure Gas Wells, a report of NACE Task Group T-1B-1 on High Pressure Well Completion and Corrosion Mitigation Procedure, W. F. Oxford, Jr., Sun Oil Co., Beaumont, Tex., chairman, and E. H. Sullivan, United Gas Co., Shreveport, La.

Offshore Corrosion

O. L. Grosz, The California Co., Harvey, La., chairman; N. R. Dunne, Shell Oil Co., Westwego, La. vice chairman.

Offshore Coatings Application Developments, by Jack Eggleston, Vapor Honing Company, Inc., Houston.

Paint Maintenance of Offshore Equipment, by R. M. Robinson, Continental Oil Co., Houston.

Aluminum Anodes for Cathodic Protection, by R. L. Horst, Jr., Aluminum Company of America, New Kensington, Pa.

Pipe Line

Marion Frank, Tennessee Gas Transmission Co., Houston, chairman; Dean Griffith, Shell Pipe Line Corp., Houston, vice chairman.

Sacrificial Anodes for Submerged Pipe Lines, by Robert G. Ransom, Tennessee Gas Transmission Co., Houston.

Deep Ground Beds, by G. P. Miles, Interstate Oil Pipe Line Co., Shreveport, La.

Corrosion Control on Aerial Pipe Line Crossing, by S. J. Bellassai, Transcontinental Gas Pipe Line Corp., Houston.

Refinery and Chemical Process Industries

W. L. Vorhies, Freeport Sulphur Co., Port Sulphur, La., chairman; R. M. Eells, Esso Standard Oil Co., Baton Rouge, La., vice chairman.

(Continued on Page 71)

More Officials Named on Chicago 59 Program

Boone Is Cathodic Protection Addition

Harlod C. Boone, co-chairman of the Cathodic Protection Symposium for the NACE 15th Annual Conference is supervisory engineer of the corrosion section in the engineering department of The Peoples Gas Light and Coke Company, Chicago, Illinois. He has been a member of NACE since 1947 and is now chairman of the Chicago Section. He has authored technical papers and gave a paper at the 1957 South Central Region meeting.

Boone

During World War II he was assigned to the test and development unit, aircraft section of the Naval Research Laboratory, Bellevue, Washington, D. C. After the war he worked for the Texas Pipe Line Co. as an electrolysis engineer, joining his present company in 1951.

New Officers Elected By Chicago Section

Chicago Section elected officers for the 1958-59 term and heard reports on the year's activities at its May 20 meeting in the Engineer's Club. New officers are: H. C. Boone, chairman; I. J. Acosta, vice-chairman; D. G. Keefe, secretary, and Wayne Schultz, treasurer. They were elected unanimously. After their election, outgoing chairman V. M. Kalhauge turned the meeting over to Mr. Boone.

I. J. Acosta in a secretarial report said the section gained 39 members during the year. Efforts of Mark Fletcher were principally responsible for the increase, he said. The treasurer's report by Mr. Keefe showed the section to be in good financial condition.

Two technical speakers addressed 72 members and guests present. Harold C. O'Brien, president and director of research of Royston Laboratories spoke on Some Factors in the Laboratory Development of Coating Properties. Kenneth Tator, head of Kenneth Tator and Associates gave an overall presentation of a logical attack on corrosion problems.

Mr. O'Brien said that extensive studies and many tests are required before a product can be marketed.

Mr. Tator stressed the importance of field testing. He discussed the use of panels and actual test applications. Surface preparation is of prime importance he said. He gave a brief explanation of a rating system for coatings which he has devised.

Many questions were asked of both speakers.

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Maps of the miles of metal pipe, power and communication cables underground in large metropolitan areas are being mapped by committees affiliated with NACE's T-7 committee.

English

Fink

Gackenbach

Ploederl

English Is Educational Lecture Co-Chairman

James L. English, Oak Ridge National Laboratory, is co-chairman of the Educational Lectures to be presented at the 15th Annual Conference and 1959 Corrosion Show. He has been a member of NACE since 1948 and has been active in technical committee work being a member of T-5A on the Chemical Manufacturing Industry, T-5A-1 on Sulfuric Acid, T-5A-5 on Nitric Acid and T-5E on Stress Corrosion Cracking of Austenitic Stainless Steel.

In his work at Oak Ridge National Laboratory, his major interests have been the corrosion of aluminum, beryllium and stainless steels by aqueous environments. He is a past-chairman of the East Tennessee Section, and is the author of a number of reports on corrosion of aluminum and beryllium by high-purity water. Oak Ridge National Laboratory is operated by Union Carbide Nuclear Co., a division of Union Carbide and Carbon Corp.

Fink Heads Corrosion Principles Symposium

Frederick W. Fink, Battelle Memorial Institute has been selected as chairman of the Corrosion Principles symposium for the NACE 15th Annual Conference and 1959 Corrosion Show to be held March 16-20, 1959 in Chicago. Mr. Fink replaces W. B. DeLong, W. I. duPont de Nemours & Co., who found it necessary to resign the chairmanship because of reassignment of duties with duPont which prevented his serving.

Mr. Fink joined NACE in 1947 and has served in various capacities. He was head of arrangements for the educational lectures for the NACE 14th An-

(Continued on Page 71)

Jeffares Accepts Pipe Line General Post

George M. Jeffares is co-chairman of the Pipe Line General symposium, NACE 15th Annual Conference. He is affiliated with the Plantation Pipe Line Company, having joined the firm as a junior engineer in 1947. He is past chairman of the Atlanta Section, is secretary-treasurer of the Southeast Region and has been a member of NACE since 1948. Prior to joining Plantation Pipe Line Company, he served with the U. S. Army Quartermaster Corps, petroleum testing laboratory, Caven Point, N. J. He attended Georgia Institute of Technology and Mississippi State College, receiving his BS in chemical engineering from the latter school in 1945.

Jeffares

Mercer Accepts Post On Utilities Symposium

C. L. Mercer, co-chairman of the Utilities Industry symposium for the 15th Annual NACE Conference has been working for the Southwestern Bell Telephone Company since 1933. In 1952 he was loaned to Western Electric Company to work on the Distant Early Warning system in Alaska. On his return in 1953 to Houston he was transferred to the division staff to work on corrosion problems of the division. He is one of the original members of the National Association of Corrosion Engineers an a member of various subcommittees. He has been active in the Houston Corrosion Control Committee as chairman, and has been very active in NACE Technical Committee work for many years. He is currently chairman of Group Committee T-7, Corrosion Coordinating Committee and T-7D, South Central Region Corrosion Coordinating Committee and is vice chairman of Task Group T-4B-5 on Non-Metallic Sheaths and Coatings.

Mercer

Chicago Committeemen Named for Conference

J. D. Oppenlander, Enterprise Paint Mfg. Co., and R. E. Bowers, Industrial Coatings Corp., are members of the Local Arrangements Committee for the NACE 15th Annual Conference and 1959 Corrosion Show to be held in Chicago, March 16-20. D. B. Sheldahl, Sinclair Research Labs., is the committee chairman.

59 Corrosion Show Space Sells Fast

Twenty companies have signed contracts for exhibit space at the National Association of Corrosion Engineers' 15th Conference and 1959 Corrosion Show to be held in Chicago, March 16-20.

Following are companies which have signed contracts to exhibit:

Aluminum Company of America
Amercoat Corporation
Apex Smelting Company
A. M. Byers Company
Carboline Company
Philip Carey Manufacturing Co.
Coast Paint & Lacquer Co.
Crane Company
Crest Instrument Company
Dearborn Chemical Company
Goulds Pumps, Incorporated
Johns-Manville Sales Corp.
National Carbon Company
Charles Pfizer and Company, Inc.
Rust-Oleum Corp.
Shell Chemical Corp.
Shell Oil Company
Standard Magnesium Corp.
Valdura Division,
American Marietta Company
Visco Products Company

Fink Heads—

(Continued From Page 70)

nual Conference held in San Francisco, March 1958. He is a past chairman of Technical Committee T-3 on General Corrosion Problems and presently is serving on the ISCC Subcommittee on Relations with Foreign Technical Organizations.

He has been with Battelle Memorial Institute since 1938, joining the staff as a corrosion engineer. Last year he was made chief of the corrosion research division at the institute.

Ploederl Named Paper Industry Co-Chairman

F. J. Ploederl is co-chairman of the Paper Industry Symposium for the NACE 15th Annual Conference. He has had extensive experience in NACE, and is now a director of the Eastern Wisconsin Section. He has been in corrosion control work for more than 20 years, principally in the formulation and application of highly resistant coatings.

He has presented numerous papers on corrosion, and has participated in short courses on corrosion at the University of Wisconsin and Case Institute of Technology and has taken part in national and regional meetings of NACE. He is a business partner in the Wisconsin Protective Coating Co., Green Bay, Wis., where he is in charge of coating research and development.

Gackenbach Added to Coatings Symposium

R. E. Gackenbach, co-chairman of the Protective Coatings Symposium for the NACE 15th Annual Conference also is active in NACE technical committee work. He is vice-chairman of T-5D on

(Continued On Page 72)

San Joaquin—

(Continued From Page 69)

to re-examine during visits in future years, the effectiveness of corrosion preventive programs.

Among the scheduled exhibits are cathodic protection of oil well casing and pipelines, tank interiors, glycol dehydrator units; process plants, interior tank coatings, hot potassium carbonate process for carbon dioxide removal and allied corrosion problems;

Chemical inhibitor application in deep gas lift wells, chemical inhibitor control in pumping wells and pipeline coatings.

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NACE has published more than 75 reports of technical committees since 1950.

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More than a thousand NACE members and 246 technical advisers are members of NACE technical committees.

New Orleans—

(Continued From Page 69)

The Use of Inhibitors in Process Industries, by Roy Comeaux, Humble Oil and Refining Co., Baytown, Texas.

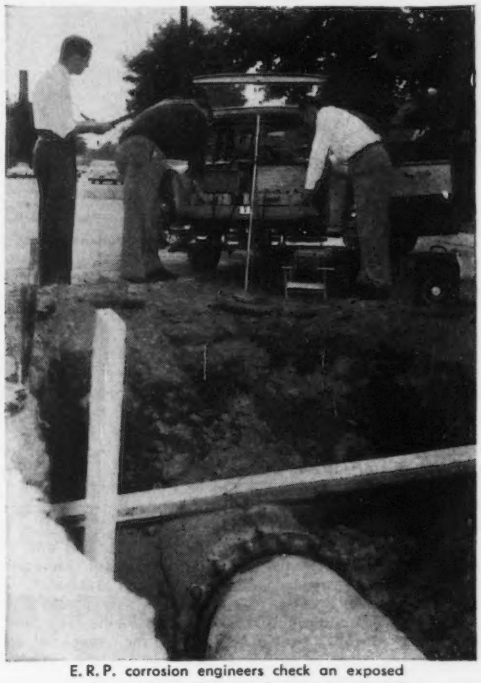
Plastic Materials of Construction, John J. B. MacKenzie, Haveg Industries, Wilmington, Del.; Use of Silicone in Refining and Process Industries, by Max Levenworth, Dow Corning Co., Dallas.

Application of Glassed Steel Equipment in Corrosive Service, by Robert E. Smith, Pfaudler Co., Rochester, N. Y.

Chloride Stress Corrosion Cracking of Austenitic Stainless Steel, by J. P. Ingalls, G. L. Floyd, R. B. Rosene, Dowell, Inc., Tulsa, Okla.

Canico Process and Materials of Construction, by C. S. Simons, Cuban American Nickel Co., New Orleans.

Engineering PLUS . . . makes the difference in pipeline cathodic protection



E. R. P. corrosion engineers check an exposed leak area. Here they correlate pipe potential and line current measurements for electrolysis.

It takes a lot of know-how to protect a pipeline from corrosion. That's why corrosion engineers at E.R.P. keep abreast of the latest instrumentation. Whether they are protecting an old pipeline or preventing corrosion on a new line, they use every modern method to be sure each cathodic system is as effective as possible.

That's what makes the difference in E.R.P. cathodic protection: engineering when the cathodic system is designed; when it's installed; when periodic corrosion surveys are made to check for environmental changes.

If you are looking for pipeline protection, E.R.P. is ready to serve you. For full information write for Bulletin E-47.27.

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TECHE SECTION'S Second Annual Short Course at Lafayette, La. was given by 20 instructors of whom 10 are shown in the top photograph. They are from left to right: C. J. Fritts, Socony Paint Products Co.; Wayne A. Johnson, Corrosion Rectifying Co.; B. P. Goodman, Tube-Kote, Inc.; Ned C. Stearns, The D. E. Stearns Co.; M. J. Olive, Arkansas Fuel Oil Corp.; Stuart G. Kershner, Texas Pipe Line Co.; Joseph E. Rench, Napko Corp.; R. A. Legault, Sun Oil Co.; M. A. Luby, Tretolite Co.; Lee R. DeRouen, Union Oil and Gas Corp. of Louisiana.

Other speakers on the program not shown here were: Dorsey R. Fincher, Tidewater Oil Co.; J. C. Spalding, Jr., Sun Oil Co.; Thomas F. P. Kelly, Mavor-Kelly Co.; W. H. Stewart, Sun Pipe Line Co. and past president, NACE; Herbert A. Robinson, Cities Service Co.; R. J. Kuhn, consultant; Norman Hackerman, University of Texas; A. W. Peabody, Ebasco Services, Inc.; J. J. Picarazzi, Cities Service Refining Corp.; and E. H. Hurst, Jr., National Aluminate Corp.

In the bottom photograph are members of the short course committee, in the usual order: First row, Al Prats, Tube-Kote, Inc., chairman, entertainment; Frank Shofner, Aquaness Dept., Atlas Powder Co., chairman, registration; John D. Stone, Sunray Mid-Continent Oil Co., chairman, planning and director of course; Sam Fairchild, Texas Pipe Line Co., speakers committeeman; G. M. Harper, Jr., Union Oil Co. of California, planning and program committeeman; Lee R. DeRouen, Union Oil and Gas Corp. of Louisiana, speakers committeeman; Wayne Grant, Jr., The Texas Co., registration committeeman.

Back row: O. L. Bassham, Tretolite Co., planning and program committeeman; John Selleck, Nocor Chemical Co., chairman, publicity; Paul Bercegeay, Southwestern Louisiana Institute planning and program committeeman; Max I. Suchanek, Dowell, Inc., Teche Section chairman and planning and program committeeman; Phil Brock, Dowell, Inc., registration committeeman and chairman, housing and meals; Vernon Sibille, The Superior Oil Co., registration committeeman; Jack Donnelly, Plastic Applicators, Inc., speakers' committeeman.

Committee members not shown are: Joe Sablatura, Gulf Oil Corp., entertainment committeeman; Nathan James, The Texas Co., housing and meals committeeman and Bill Odom, Shearon Co., housing and meals committeeman.

120 Register for Teche Short Course

Teche Section's Second Annual Corrosion Control Short Course, held in cooperation with Southwestern Louisiana Institute, Lafayette, La. attracted 120 registrants to hear a 3-day program by 20 speakers. This represented a gain of about 10 percent over registration of the first course in June, 1957.

At the May 22 section meeting Jack Kinley, Houston spoke about a new tubing caliper instrument.

D E A T H S

Clifford D. "Shorty" Cobbett, an ememployee of Hill, Hubbell Co. Division of General Paint Corp., Cleveland for 28 years, died May 9 of a heart attack at Pittsburgh airport. A well-known figure in the pipe coating field, he rose from plant laborer to district sales manager. He joined NACE in March, 1948. He is survived by his widow, a brother and four sisters.

NEWS DEADLINE FOR CORROSION

News intended for publication in CORROSION should be in Houston not later than the 10th of the month preceding month of publication. When events occur at or near this date, it sometimes is possible to hold space for news stories, provided advance notice is given. An estimate of the amount of space required should be included in the advance notice.

Spalding Heads 1960 Conference Committee

J. C. Spalding, Jr. has accepted the position of General Conference Chairman for the NACE 16th Annual Conference to be held in Dallas, Texas, March 13-19, 1960.

Spalding

Mr. Spalding, Sun Oil Co., has been active in NACE affairs for more than 10 years. He is a past chairman of Technical Unit Committee T-1K on Inhibitors for Oil and Gas Wells. He was successively elected to positions of secretary-treasurer, vice chairman and chairman of the South Central Region and now holds the latter position. He also once served as chairman of North Texas Section.

Before joining Sun Oil Co. in 1947, he was on the faculty of Southern Methodist University.

Gackenbach Added–

(Continued From Page 71)

Plastic Materials of Construction. He is a past chairman of the committee and also of Task Group T-5D-6 on The Use of Plastics in the Presence of Organic Chemicals. He served as chairman of the Chemical Industry Symposium at the NACE 14th Annual Conference held in San Francisco last year.

Mr. Gackenbach is associated with the Organic Chemicals Division of American Cyanamid Company, Bound Brook, N. J. as divisional materials engineer. In this position he evaluates, selects and specifies materails of construction and makes recommendations for design fabrication and installation of process equipment. He has a BS in metallurgical engineering from Lehigh University and is a member of NACE and ASM.

Alabama Journal Started

Birmingham Section NACE is a member of the Birmingham and Jefferson County Engineering Council which is sponsoring a new monthly engineering periodical for the state of Alabama.

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The Ten-Year Index to CORROSION 1945-54 indexes over 3500 pages published in those years.

ANY WAY YOU LOOK AT IT

Standard's HIGH CURRENT Anodes deliver more protection at less cost!

As every corrosion engineer knows, it is the current delivered by magnesium anodes that stops corrosion. Ohms Law reads "Current equals volts divided by resistance." Therefore, reducing the resistance increases the current output and the protection delivered by an anode. The resistance of a magnesium anode decreases rapidly by extending the length of the anode.

Standard Magnesium now offers, at no additional cost, a line of HIGH CURRENT output anodes of increased length. These HIGH CURRENT anodes produce 50% more current output than conventional anodes. Furthermore, that H-1 alloy delivers the maximum possible life and protection has been field proved over a decade in millions of installations.

With this new HIGH CURRENT anode you save on installation as well as original costs since four HIGH CURRENT anodes will deliver the current of six conventional anodes.

Be sure you are getting the maximum return for your dollar investment. Insist on Standard Magnesium HIGH CURRENT anodes.

For complete information describing advantages of HIGH CURRENT *anodes write for FREE booklet CH58.*

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MINIMIZES CORROSION in Tanks—Vats—Pipes—all Containers, any Exposed Metal
PROTECTS AGAINST highly concentrated Acids—Fumes—Caustics—Alkalies Abrasives—Heat
PROVEN SUPERIOR in Resistance—Flexibility—Long Life—Reduction of Deterioration Under the Most Extreme Corrosive Conditions
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NACE to Participate in '59 Conference on Stress Corrosion Fracture at Pittsburgh

National Association of Corrosion Engineers will participate with other societies in the conference on Physical Metallurgy of Stress-Corrosion Fracture, to be held at the Mellon Institute, Pittsburgh, April 2-3, 1959. W. B. Brooks, The Dow Chemical Co., is the official representative of NACE.

The conference is sponsored by the Corrosion-Resistant Metals Committee of the Institute of Metals Division and the Pittsburgh Section of Metallurgical Society of the American Institute of Mining, Metallurgical and Petroleum Engineers. Cooperating societies in addition to NACE are The Electrochemical Society and the American Society for Testing Materials.

Presentation and discussion on a broad basis of recent fundamental advances in stress-corrosion cracking is the purpose of the conference. The meetings have been organized around the following general subjects: 1) Introduction and Background. 2) Theoretical Aspects of Stress Corrosion and Fracture. 3) New Experimental Advances in Stress Corrosion and Fracture. 4) Mechanisms of Stress-Corrosion Cracking Including Environmental and Metallurgical Aspects and the Behavior of Specific Materials.

Emphasis will be placed on the physical metallurgical, surface chemical and solid state physics aspects of the phenomena.

Meetings will be of the discussion type. Speakers are to present only summaries of their papers, emphasizing what is new and significant. It is planned to preprint the papers so those participating can be informed and ready to discuss the subject and exchange scientific information.

The proposed technical program will present under Introduction and Background: a) Significance of the stress-corrosion problem. b) characteristics of stress-corrosion cracking.

Under Theoretical Aspects of Stress, Corrosion and Fracture: a) relationship of microstress to fracture (at or near solid-fluid interfaces). b) thermodynamic relationship between stress and chemical potential. c) relationship of surface topology and structure to environment.

Under Experimental Aspects of Stress, Corrosion and Fracture: a) role of the corrosion product. b) stress and microtopology. c) stress and electrode potential.

The preceding three symposia will be presented April 2.

Planned for April 3 in a symposium on Mechanisms of Stress-Corrosion Cracking: a) environmental aspects (two papers). b) metallurgical aspects (five papers). c) behavior of specific materials (two papers).

Aluminum Alloys in High Purity Water Topic at N.Y.

Aluminum Alloys for Handling High Purity Water was the title of a talk by Wayne W. Binger, scheduled to be delivered to the Metropolitan New York Section meeting, May 20 in the Hotel Shelburne.

In a summary of his talk Mr. Binger, who is associated with the Chemical Metallurgy Division, Aluminum Research Laboratories, said that industry has developed an increasing demand for large quantities of high purity water. Utilities are requiring large amounts of high purity water to accompany increasing temperatures and pressures in their steam cycle operations. This recent surge has been supported by additional critical requirements by the nuclear energy industry. For many years, chemical companies, research or industrial laboratories, food manufacturers and pharmaceutical houses have required high purity water in some phases of their operations.

Mr. Binger summarized some of the performance records accumulated over the past 20 years on high purity water systems and the alloy developments currently under way to accommodate the demands of the nuclear energy field.

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North Central Region will hold its 1958 meeting October 15-17 at Cincinnati.

Whiteneck Talks at L.A.

The importance of corporate members to National Association Corrosion Engineers was stressed in an address by L. L. Whiteneck, Plicoflex, Inc., NACE president to the Los Angeles Section, May 28. This was the last meeting of the section until September.

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handling problem solved by BART
LECTRO-CLAD® pipe
At the Muscle Shoals chlorine-caustic soda plant of Diamond Alkali, one of the largest of its kind, BART Lectro-Clad pipe carries hot caustics to storage tank—efficiently and economically.
IF YOU HANDLE CORROSIVES OF ANY KIND—
Investigate BART Lectro-Clad pipe and fittings. Providing a smooth, ductile, pore-free coating of nickel in its purest form, they combine high strength, heat tolerance, and remarkable ease of fabrication and maintenance. Most sizes readily available, others to order. Write distributor for full technical data. Michigan Pipe Co., 2415 Burdette Ave., Ferndale, Michigan.
Part of 7000' Bart Lectro-Clad pipe running from Diamond Alkali plant to river storage tank.
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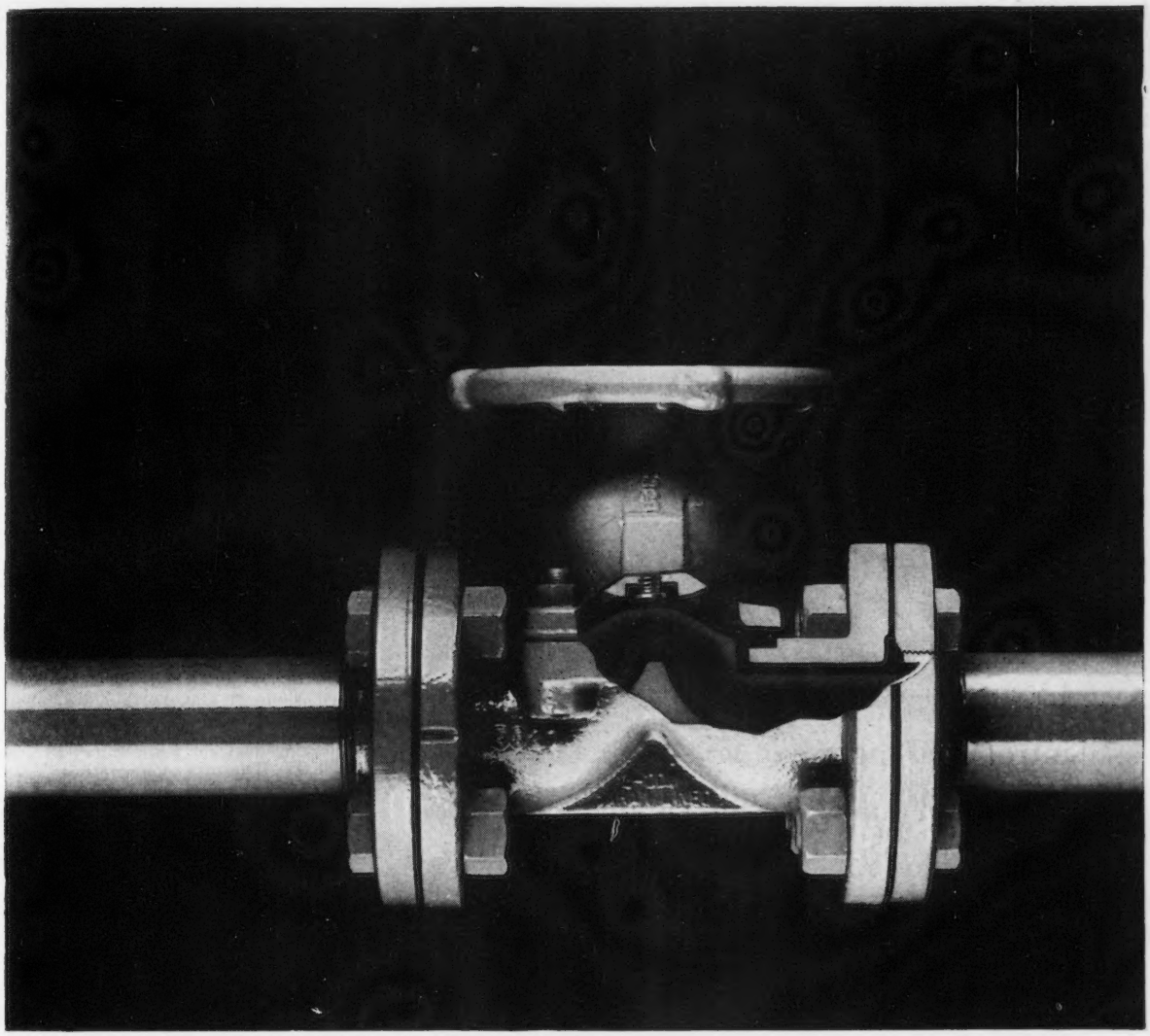

Corrosion protection is continuous in saran lined pipe—liquid never touches metal.

Here's why Saran lined pipe offers long range economy

It's rigid steel pipe . . . lined with corrosion-resistant saran . . . keeps shutdowns to a minimum for years

Looking ahead? Do your plans call for a complete corrosion-resistant piping system with a low total installation cost . . . a system that requires a minimum of maintenance . . . that's simple to modify . . . that can be fabricated in the field?

Then it will pay you in every way to look into the genuine economy of a complete system of saran lined pipe.

First, consider the natural advantages of the new gray saran lining itself. Its lower coefficient of thermal expansion and contraction more closely approaches that of steel. This provides a broader operating temperature range and greater resistance to thermal cycling. It can be installed in systems with operating pressures from full vacuum to 300 p.s.i. and temperatures up to 200° F. Add to these advantages the immediate availability of saran lined pipe, valves, pumps and fittings and you have an ideal piping system that can be installed without trouble, waiting or hidden costs.

If your plans call for lined tanks, you'll want the advantages of Saraloy® 898 tank lining added to your saran lined pipe system. Get the complete story on how it will pay you to install a complete saran and Saraloy 898 lined system. THE DOW CHEMICAL COMPANY, Midland, Michigan.

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Metallic Coatings Is Topic At San Francisco July 2

Corrosion and the Protective Value of Metallic Coatings was the title of a technical talk delivered before the San Francisco Bay Area Section meeting June 2 in Berkeley. C. H. Sample, International Nickel Co., development and research section was the speaker.

The meeting was held in conjunction with the meeting of the local section of the American Society for Metals and was the last until September. Twenty-two members and three guests attended.

For the May 14 section meeting, the technical subject was Corrosion Problems in the Canning Industry, by Norman Buell, California Packing Corporation.

Welding Copper-Base Alloy Tubes Is Scheduled Topic

Mechanical Effects Resulting From Welding Copper-Base Alloy Tubes to Tube Sheets was the title of a talk scheduled for the Kanawha Valley Section meeting May 22 with Lowell Hawthorne, manager, welding service, research department, Revere Copper and Brass, Inc. as speaker.

The board of governors of the section, composed of section officers and committee chairmen was slated to convene prior to the evening meeting. Arrangements were made with the Marietta Country Club for members to play golf preceding the section meeting. The section nominated A. C. Hamstead to represent it in Northeast Region during 1958-59.

When Was Zinc Chromate First Used in Corrosion Inhibitors?

Over 10 years ago, in 1947, Wright introduced the use of zinc, for corrosion control, in a new Wright product called Penechrome Z. Since then other Wright Penechromes, containing zinc chromate and organic additives, have proved in years of field service the greater effectiveness of zinc-containing corrosion inhibitors. Wright research, as always, will continue developing new approaches to the solution of your water side corrosion problems.

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30 Years' Experience Proves Cathodic Protection's Value

More than 30 years of experience prove that cathodic protection of bare and poorly coated underground pipe lines is profitable. This was the conclusion from the remarks of Max F. Slather, United Gas Pipe Line Co., San Antonio before a meeting of Alamo Section May 20. Mr. Slather, who related some of the experience his company has had protecting underground plant in his district, showed in text and graphically that leaks have consistently diminished in frequency on every line on which cathodic protection has been applied.

Much of the pipe in the San Antonio district is of advanced age. Over 700 miles is 27 years of age.

Although cathodic protection of the system first began in 1936 using wind driven generators as a source of current, a planned cathodic protection program was not started before 1940, shortly after which it was interrupted by World War II. The program was resumed in 1947 at an accelerated rate. The company has spent more than $900,000 on cathodic protection since.

Mr. Slather estimated savings in leak losses alone in nine years to be about $3,270,000. Since cathodic protection during the nine years cost $900,000, a net saving over costs is estimated to be $2,368,000. The rate of increase in leaks before cathodic protection was about 14 percent. In 1956, this rate was reduced to 6 percent. On some well-coated lines on which cathodic protection was installed in the beginning, he said, there has never been a leak.

With respect to the contention that coating pipes results in accelerated pitting at points, Mr. Slather said that leaks of this kind are preferred to general wastage of pipe thickness which may result in catastrophic damage. He also said that when cathodic protection is first installed a rash of small leaks usually follows, but that the leaks diminish rapidly thereafter.

Langlois Is Chairman of Greater Boston Section

New officers for the Greater Boston Section were elected and installed at the May 21 meeting in Brookline, Massachusetts. New officers are Walter E. Langlois, chairman; Benjamin F. Barnwall, vice-chairman and Manson Glover, secretary-treasurer.

Other section officers for 1958 are George H. Hunt, chairman of the program committee; Charles H. Curry, Jr., chairman of the membership committee and John Swift, chairman of the NACE corporate membership committee.

Technical speaker for the meeting was Harvey S. Miller who spoke on spray coating metals.

Activities at the NACE 14th Annual Conference were described in two brief reports. A request was made for authors to volunteer papers for the NACE 15th Conference in Chicago, March 16-20, 1959.

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NACE Now has 56 local sections.

Panel Discusses Successful Use of Corrosion Inhibitors

Corrosion Inhibitors was the subject of a panel discussion at the technical session of the June 10 Houston Section meeting. Members of the panel presented different requirements in their special application of an inhibitor, and spoke of a new approach on the testing and developing of inhibitors.

Houston Section members welcomed new officers for 1958-59 and gave outgoing chairman Joy Payton and other outgoing officers a standing ovation. New officers are: W. A. Wood, Jr., Products Research Service, Inc., chairman; C. B. Tinsley, Southwestern Bell Telephone Co., vice chirman; and O. A. Melvin, Carboline Co., secretary-treasurer.

In the opinion of W. B. Hughes, Tretolite Co., many inhibitors fail because the corrosion engineer does not keep foremost in his mind specific requirements demanded under each individual case. Weight loss tests, deposit of inhibitor film, and many other broad criteria don't exactly mean much when it comes to special conditions presented by each job, he maintained. However, Mr. Hughes said he was confident that sometime in the future some means would be found to develop an inhibitor which by slight field modifications would be suitable for almost every requirement. He emphasized he knew of no such inhibitor at present.

R. V. Comeaux, Humble Oil and Refining Co. presented slides showing corrosion in refining equipment. Even though inhibitors were used, corrosion was severe. Mr. Comeaux said he did not know whether or not inhibitor came into contact with the corroded parts.

He pointed out that in some instances, designers engineer equipment with baffles, sharp turns and other means of separating components of fluids and materials being processed. He felt that it was quite likely an inhibitor under some circumstances would in this way be removed from the medium and lose its effectiveness.

D. R. Fincher, corrosion engineer for the southern division of Tidewater Oil Co., said results from using the squeeze method of inhibition indicated it was a good one. Records on wells showed only a few cases where results were disappointing. He pointed out that getting inhibitor fluid into a well is not a simply a matter of pouring it down the hole.

C. C. Nathan acted as moderator for the panel, and referred questions presented to panel members after they had delivered their short talks.

At the May 13, picnic meeting, 125 adults and 58 children swam, enjoyed barbecued chicken and joined in informal dancing. Shirts, gloves (both for club heads and hand gloves), golf balls and golf tees were awarded winners of the blind bogey tournament. Jack Rowe won the handicap with a score of 60. Bert Owens was low golfer with a low gross score of 78.

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NACE has published more than 75 reports of technical committees since 1950.

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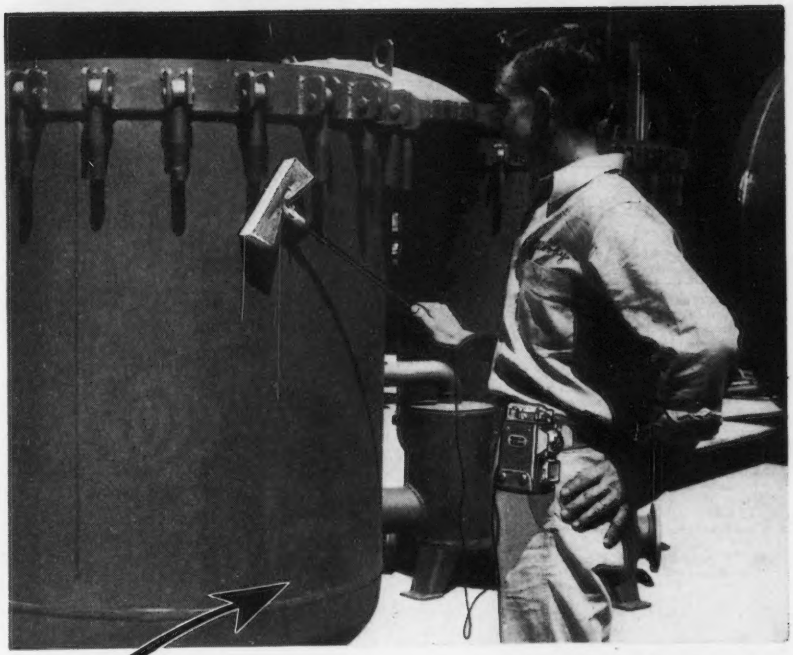
More than a thousand NACE members and 246 technical advisers are members of NACE technical committees.

HOW TO INSPECT THIN FILMS ON CONDUCTIVE SURFACES



When the tapwater wet sponge at the end of the wand in the operator's hand reaches a holiday in the coating of this vessel, a bell signal registers in the detector hanging at the operator's side. Circuit is completed through a wire attached to bare metal of the vessel.

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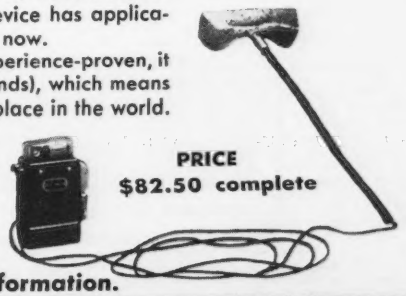
This makes the T & R Model M-1 Detector ideal for use on tanks, tubes, pipes or any similar coated container where corrosive liquids or gases are to be transmitted or stored. Undoubtedly, this new device has application in your plant or factory right now.

Scientifically-designed and experience-proven, it is lightweight as well (only 4 pounds), which means easy and rapid shipment to any place in the world.



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ABOUT NORTHEAST REGION SYMPOSIA OFFICIALS

Long corrosion experience and degrees from top technical schools in the nation are almost a common denominator for chairmen of symposia to be held at the Northeast Region Meeting, October 6-8.

THEORY AND PRINCIPLES

Chairman is Daniel Cushing, consulting metallurgical engineer, Boston, Mass. A native of Massachusetts, he was educated at the University of Virginia, Yale University and the Massachusetts Institute of Technology.

Among his past work have been inventions in metallurgical processes and equipment. He was one of the early members of NACE, joining in 1945. Included in his corrosion studies are original work in the corrosion of ancient bronzes.

He is chairman of NACE Technical Group T-4F-1 and chairman of the Technical Practices Committee of the Greater Boston Section, NACE. He is also a member of the following NACE technical organizations: T-4E on Corrosion by Domestic Waters, T-4E-1, on Hot Water Tank Corrosion, T-4F on Materials Selection for Corrosion Mitigation in the Utility Industry, and T-4F-2, Materials Selection in the Electric Industry.

MARINE CORROSION

L. M. Mosher, Bethlehem Steel Corporation, shipbuilding division, Quincy, Massachusetts, is chairman. He has been with the company since 1944, working in the field of corrosion, corrosion preventive measures and marine biology. After graduating from Massachusetts Institute of Technology in 1929, he became a member of the school's research staff. He is a member of NACE Technical Unit Committees T-3H on Tanker Corrosion and T-6C on Protective Coatings for Resistance to Marine Corrosion.

CATHODIC PROTECTION

Boris H. Tytell, a supervisory chemist with the Boston Naval Shipyard is chairman. Mr. Tytell has had considerable experience in the comparative evaluation of both galvanic anodes and anodes for impressed current systems. He has specialized in cathodic protection for several years, and is a member of NACE Unit Committee T-3G on Cathodic Protection, T-2B on Anodes for Impressed Currents and Task Group T-3G-1 on Cathodic Protection of Hull Bottoms of Ships. He is a graduate of Brooklyn Politechnical Institute.

PROTECTIVE COATINGS

J. Dwight Bird, The Dampney Company, Hyde Park, Massachusetts is chairman. He has worked for thirty years in the field of corrosion control through use of protective coatings, with particular emphasis on power and mechanical service. He was educated at the University of Dallas, Texas and has worked with the General Electric Company and Ebasco Services, Inc., operating properties in construction and maintenance programs.

He is a member of several technical societies and has had experience in technical meeting work; being general chairman of the 1958 National Engineering Managment Conference which was co-sponsored by ASME and AIEE. He is now vice-presfdent and director of The Dampney Company. He is past chairman of the NACE Boston Section and of the Northeast Region and is a member of Technical Unit Committee T-6D on Industrial Maintenance Painting.

UTILITIES INDUSTRY

E. R. Perkins, chairman, is Protection Engineer on the staff of the Chief Engineer, New England Telephone and Telegraph Company. He became associated with the company shortly after graduation from Massachusetts Institute of Technology. His present work covers the field of electrolysis and corrosion on a staff basis and he is a member of NACE Technical Unit Committee T-7A. Northast Region Coordinating Committee, and of the Greater Boston Electrolysis Committee.

GENERAL CORROSION

Carlton L. Goodwin, Portland Pipe Line Corp., is chairman. He has presented many papers before the NACE, API and AGA on pipe line corrosion control.

Since 1932, he has served in several capacities with his firm, both in operations and engineering. He presently is senior corrosion engineer with Portland Pipe Line Corp. He holds a BS degree in chemical engineering from the University of Maine.

Four Technical Papers Are Added to Boston Program

Four technical papers have been added to symposia for the Northeast Region Meeting to be held in Boston Massachusetts, October 6-8, 1958.

New papers and authors are, in the Protective Coating symposium, Session Two, Polyurethane Protective Coatings —Properties and Applications, by E. R. Wells, Mobay Research Laboratory; Another paper will be delivered by D. K. Priest, the Pfaudler Co.

In the Utilities Industry symposium, K. G. Compton, Bell Telephone Laboratories will present Instruments for Corrosion Testing, Uses and Limitations.

In the General Corrosion symposium, the paper, Zinc in Marine Environments, will be delivered by E. A. Anderson, New Jersey Zinc Co. Other minor corrections and changes are being made in the program as meeting officers round it into shape.

Murray M. Jacobson, Watertown Arsenal Laboratories, is chairman of the technical program.

Committees Schedule Sessions at Boston

Six NACE technical committees will meet during the North Central Region meeting to be held in Cincinnati, October 15-17. According to the tentative schedule released by Sylvan B. Falck, chairman of the technical program committee, the committees will meet as follows:

Wednesday am, October 15: Technical Committee T-5B on High Temperature Corrosion; Technical Committee T-3F on Corrosion by High Purity Water. Wednesday pm: Technical Committee T-6F on Protective Interior Linings, Application and Methods.

Thursday am, October 16: Technical Committee T-7B, North Central Region Corrosion Coordinating Committee; Technical Committee T-5A-4 on Chlorine (Corrosion Problems in the Process Industries). Thursday pm: Technical Committee T-5A-6 on HF Corrosion (Corrosion Problems in the Process Industries).

Caliper Surveys Topic at Longview

East Texas Section held its last meeting of the season, May 27 in Longview, Texas. T. A. Kelly, Otis Pressure Control, Dallas, gave a very informative talk on the equipment, techniques and interpretations of caliper surveys and statistical and graphical methods of evaluating the data obtained. Fifteen members and 15 guests attended the meeting.

Next section meeting will be September 23 in Longview. The program for this meeting has not been selected. However, on October 28, Tom O. Stephens of Amercoat Corp., Houston, will speak on Applications and Limitations of Protective Coatings. This meeting also will be held in Longview.

At the April 23 meeting, Kenneth Tator of Kenneth Tator Associates, spoke on Corrosion Preventive Coating Information. He divided coatings into types, indicating the nature and degree of protection offered by the various types. Temperature, pH and solvent limitations and applications of the various types of coatings were discussed, as were economics of the various types.

Corpus Christi Session on External Corrosion Held

Oil and Gas Well External Corrosion and Cathodic Protection was the technical topic scheduled for meeting of Corpus Christi Section, May 27 at Pike's Grille. The program was slated to follow a dinner and a social hour.

Wayne A. Johnson, Corrosion Rectifying Co., Houston, Texas, was the scheduled speaker. He heads a firm which specializes in designing and building rectifier and galvanic anode systems for the oil and gas and construction industries.

The section will adjourn for the summer months not to meet again until September, when a barbecue will be held.

Film on Ductile Iron Is Shown at Rochester

Election of officers and the showing of a film, Ductile Cast Iron were scheduled for the Genessee Valley Section meeting in the Pfaudler Research Laboratory, Rochester, N. Y., May 27. W. G. Ettinger, Casting Division of American Brake Shoe Co. was selected to explain the film and answer questions afterward. The meeting was the last one scheduled until next season.

You're Money Ahead to MEASURE PIPE PROTECTION WITH A CALENDAR

How should pipe protection be measured? By first cost? By ease of application? By appearance?

With all the claims made for protective tapes, too often the most important consideration is overlooked—the simple point of how long and how well it will protect the pipe.

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After all, hot-applied coal tar has proven over the years to be the most dependable and enduring protection. And because TAPECOAT is a hot-applied coal tar coating in tape form, it offers the same lasting protection.

A TAPECOAT sales and service engineer is available at all times to assist you on any corrosion problem and on the various applications of TAPECOAT.

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Pipe	**Tanks**
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Stanley

Treves

Editing, publishing and mailing NACE Corrosion Abstract Punch Cards is the responsibility of Nicole Treves and Bobbie Stanley, members of the NACE Central Office Staff.

The abstract card service was instituted in 1951 by NACE after years of study by corrosion experts and NACE officials. These persons, some of them top executives in their own companies while holding offices in NACE, shaped the service to what they believed to be the need of corrosion engineers.

Approximately 15,400 abstracts have been published on punch cards since 1951. Many abstract card shipments are sent to subscribers in other countries. There are several hundred topical classifications in the index used on the cards.

Miss Treves, in charge of the abstract service since March, classifies the abstracts according to the NACE Abstract Filing Index. Original abstracts are obtained from 23 different sources from which they are selected by corrosion experts comprising a special selection group. After the abstracts have been classified, Miss Stanley types them on special offset duplicator plates. After they are proofread, they are printed, collated, boxed and mailed.

Mailing dates to be set and met, correspondence with subscribers to be carried on, records to be kept and the many other details to be handled, keep these two members of the Central Office staff busy.

Miss Treves, a recent resident of the United States, came here from Egypt. She attended Lycee Francais de Caire, and holds a bachelor of science degree in chemistry from the American University of Cairo. Her leisure interests are journalism, amateur theater and piano music. She speaks four languages.

Miss Stanley has been with NACE for more than five years. She became associated with NACE on graduation from North Texas State College in 1951 with a degree in business administration. Her principal hobbies are attending live theater plays, good music and art. She also likes sports and enjoys relaxing on Gulf Coast beaches.

COKE BREEZE

Backfill for Anodes

Ideally suited for use with anodes. Has a high carbon content and comes in sizes of ⅛-inch x 0 to ⅜ x ⅛ inch. In bulk or sacks. Prices on other sizes on request.

National Carbon Anodes

Magnesium Anodes

Good-All Rectifiers

WHOLESALE COKE COMPANY

PHONE GARDENDALE, ALA.
HEmlock 6-3603

P. O. Box 94 Mt. Olive, Ala.

Water Treatment Is Topic

Water treatment, particularly the problems relevant to industrial, boiler and circulating ice waters was the technical subject selected for the Central Arizona Section dinner meeting scheduled for May 9. The technical speaker selected to address the group was William Wallace, Cone & Wallace Co.

APEX *for cathodic protection*

MAGNESIUM ANODES

Corrosion control for under-ground and under-water pipelines and other metal structures regardless of all other methods used.

Anode folders or technical consultation with our engineers available upon request.

APEX Anodes are now available in 5 lb., 10 lb., 17 lb. and 32 lb. sizes. You may order bare anode with or without wire, or complete packaged anode with wire and back-fill ready for installation.

APEX SMELTING COMPANY

CHICAGO CLEVELAND LOS ANGELES

Southwestern Ohio Section Tours Plant

Plant tours, election of officers, picnics and obtaining corporate members have been varied activities of Southwestern Ohio Section during the past few months. The section scheduled its picnic for May 23 at Clifty Falls, Indiana State Park, a short distance west of Madison, Indiana. Selected as a landmark for the rendezvous point for the picnic were the 710-foot smokestacks of the gigantic Clifty Creek electric generating plant of 1,200,000 kilowatts capacity, owned by the Indiana-Kentucky Electric Corp. A tour of the plant was the first event scheduled. Also on the program was a visit to Clifty Falls park with a dinner at the park inn. A brief business meeting with installation of officers was scheduled next. Motion pictures produced by International Nickel Co. on fundamentals of corrosion concluded the scheduled events.

The corporate membership drive was discussed at the April 29 meeting in Dayton, Ohio, by W. J. Kretschmer, Columbia Gas System Service Corp. A tour of the Duriron Co. plant, laboratory and foundry preceded the meeting.

Officers elected at the April meeting were: W. E. Hare, chairman; R. L. Wood, vice-chairman and program director; S. Clifford Jones, secretary; Arthur D. Caster, treasurer and Robert F. Andres, Guy H. Cantwell, Lewis M. Lederer, R. B. Stephenson, board of directors.

Reinhart Now Heads Editorial Subcommittee

Fred M. Reinhart, National Bureau of Standards, Silver Spring, Md. has accepted the post of chairman of the NACE Editorial Review sub-committee. The committee reviews technical papers submitted for publication in CORROSION.

The committee also was increased to 23 by the addition of two new members. They are W. W. Binger, Aluminum Company of America, New Kensington, Pa. who will review papers on light metals and N. D. Greene, Electro Metallurgical Co., Niagara Falls, N.Y. who will review papers on corrosion theory.

Auto Exhaust Control Costs Are Estimated

Controlling the quality of gases exhausted from automotive equipment will be the prime goal of the Air Pollution Foundation. Cost of control by currently proposed methods will range from $50 to $85 per year per automobile. Considered are induction devices, direct flame and catalytic afterburners, nitrogen oxide eliminators, fuel changes and combinations of these devices.

Copies of the foundation's publication on the subject are available at $3 a copy from 2556 Mission St., San Marino, Cal.

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The NACE 15th Annual Conference will be at Sherman Hotel, Chicago.

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South Central Region's 1958 Conference and Exhibition will be held October 20-24 at the Roosevelt Hotel, New Orleans.

GENERAL NEWS

NBS Salt Water Studies Validate Protection Criterion

The National Bureau of Standards has completed a study of the electric potential needed to protect steel cathodically from corrosion in salt water. Data obtained under controlled laboratory conditions are expected to provide a basis for handling similar problems encountered under marine conditions.[1] It was found that the best degree of protection was achieved when specimens were held at minus 0.77 volt with reference to a saturated calomel electrode.

Normal corrosion of iron and steel is an electrochemical phenomenon. When metal is exposed to salt water, differences in electric potential develop at the surface of the metal, resulting in the formation of numerous small corrosion cells. This action causes destructive alteration of areas, known as anodes, on the metal surface where metallic ions enter the electrolyte. In applying cathodic protection, direct current from an external source is caused to flow from an auxiliary anode toward the corroding surface. This prevents positive metal ions from entering the electrolyte.

Equivalent to Other Criteria

The potential at which a metal structure should be maintained in order to prevent corrosion is a question of practical interest. Insufficient negative potential will give inadequate protection. On the other hand, maintaining a greater potential than is needed is unnecessarily costly. Some engineers are of the opinion that —0.85 volt with reference to a copper-copper sulfate electrode (equivalent to —0.77 volt with reference to a saturated calomel electrode) sometimes represents overprotection and excessive current demands. It was to study this problem that W. J. Schwerdtfeger of the bureau's corrosion laboratory undertook the present work.

An earlier laboratory investigation of corrosion in various types of soils using soil cells had shown that steel specimens maintained at —0.77 volt with reference to a saturated calomel electrode lost negligible weight in a 60-day exposure period. Also, deviations in potential electro-positive to this voltage for relatively short intervals resulted in appreciable weight loss. Specimens maintained at more negative potentials (—1.0 volt) generally showed no greater reduction in weight loss.[2]

The corrosive environment chosen for the present study was Washington (D. C.) tap water with an added 3 percent by weight of sodium chloride. This electrolyte presented no problem in the measurement of significant potentials; no special equipment was needed as the IR (voltage) drops in the salt water were negligible. All specimens were 16-inch long, 0.5-inch diameter, cold-rolled steel rods, taped at the water line and suspended vertically in the water for 60 days.

(Continued on Page 82)

THE EFFECT OF VARIOUS CORROSIVE ENVIRONMENTS ON MILD STEEL
PHOTOMICROGRAPHS OF MILD STEEL IN VARIOUS CORROSIVE ENVIRONMENTS
ANALYSIS OF CORROSION PRODUCT
PHYSICAL PROPERTIES
CHEMICAL PROPERTIES

AT NATIONAL SCIENCE FAIR, Flint, Mich. this was the sole display on a corrosion control subject. Seated on his exhibit is Ludy Harman, Ponca City, Oklahoma Senior High School, who received the U.S. Navy Cruiser alternate award. If the original recipient is unable to go, he will spend a week at sea on a special tour arranged by the Navy. Ludy is seventeen years of age.

Safety Precautions Listed for Tankers Using Cathodic Protection Against Corrosion

Precautions recommended on oil tankers with cathodic protection systems were included in a paper "Tanker Safe Practice," by C. T. Sutton, BP Tanker Company, London, England scheduled for presentation June 10 at the Tanker Corrosion Symposium of the Annual Tanker Conference of the American Petroleum Institute.

Precautions were emphasized against having magnesium anodes suspended in tanker compartments falling and causing sparks which may cause explosions. In a discussion of sparking from metals on impact it was noted that sparks of sufficient caliber to cause explosions may occur readily when one of the metals is magnesium. Aluminum impurities also have a tendency to cause sparks.

Positive venting of water-filled tanks under cathodic protection was advocated. Mr. Sutton also recommended that tanks be kept as nearly full as possible and that partly filled tanks be watched carefully. The use of electrical welding or other flame-producing equipment in the vicinity of cathodically protected tanks was called extremely dangerous. Hydrogen formed as a result of water decomposition around the anodes is extremely explosive and must be vented to air.

The author also cited corrosion structural failures inside tanks which may cause accidents, for example valve spindles or ladders. Accumulation of large and heavy pieces of scale on bulkheads and deckheads should be avoided. One explosion is reported to have occurred as the result of dumping heavy material on deck.

Pyrophoric iron sulfide apparently does not commonly occur in tankers, the author said, but to a limited extent iron sulfide may be hazardous in that it can contribute to burning of scale when welding is done and also might contribute to sparking on impact.

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Northeast Region's 1958 meeting will be held October 5-8 at Somerset Hotel, Boston.

Mechanical and Plumbing Contractors' Associations to Merge

A merger of the Mechanical Contractors Association of America, Inc. and the National Association of Plumbing Contractors has been approved by the executive committees of each organization. Reason for the merger is that fundamental changes have occurred in the industries in the past 20 years in which activities of members of each society have grown more similar. More than half the members of MCAA also are members of the National Association of Plumbing Contractors. Details of the merger will be worked out by committees appointed for the purpose. Annual convention of the MCAA was scheduled for May 20-23, that of the NAPC for June 30-July 3.

Physical Chemistry of Process Metallurgy Symposium Planned

An International Symposium on the Physical Chemistry of Process Metallurgy will be held in Pittsburgh. It is sponsored by The Metallurgical Society of AIME in cooperation with the Physical Chemistry of Steelmaking Committee of the Iron and Steel Division, the Physical Chemistry of Extractive Metallurgy Committee of the Extractive Metallurgy Division, and the Melting and Casting Committee of the Institute of Metals Division.

General topics for the four-day symposium are:

Physical Chemical Principles: a) Theory and behavior of metal solutions and of oxide phases; b) Electrochemistry behavior of fused salts and electrochemical reactions; c) Pyrochemistry reactions between slag, metal, gaseous and solid oxide phases.

Transport Phenomena: a) Principles of kinetics; reaction rates, mass and energy transport; b) Electrochemical phenomena, electrode reactions and electrolysis; c) Pyrochemical reaction mechanisms.

Application of Physical and Chemical Principles to Metallurgical Processes—Thermodynamics, Kinetics, Mass and Energy Transfer: a) Communition; b) Leaching, solution and phase separation; c) Roasting and agglomeration; d) Reduction and smelting; e) Gaseous, liquid and solid phase refining; f) Casting and solidification.

Application of Operations: Research and statistical methods to process control.

Technical papers in all areas of process metallurgy are invited for presentation at this symposium. In addition to having reports on the results of new basic research, it is planned to emphasize in the program the use of fundamental facts for obtaining better understanding and better control of the new and the traditional methods for producing the various metals.

Deadline for submission of papers is January 1, 1959. Anyone planning to participate in the symposium should write to Professor John F. Elliott, Room 8-109, Massachusetts Institute of Technology, Cambridge 39, Massachusetts, who is serving as programs chairman. Professor C. Law McCabe of Carnegie Institute of Technology, is conference chairman.

A proceedings of the symposium will be issued.

The Metallurgical Society of AIME is a constituent unit of the American Institute of Mining, Metallurgical, and Petroleum Engineers.

NBS Salt Water—

(Continued From Page 81)

Equipment Is Described

Currents and potentials were measured with both recording- and indicating-type instruments. Protective potentials were controlled to within ±5 mv by an electronic balancing unit which actuated a motor-driven voltage divider that applied current to the specimens. Currents required to maintain these potentials were compared with the currents indicated by changes-in-slope, referred to as "breaks," of cathodic polarization curves obtained on control specimens. The polarization curves were obtained automatically by using a synchronously driven voltage divider and a two-pen (current and potential) recorder.

Under both stagnant and aerated exposure conditions, the best degree of cathodic protection was attained at —0.77 volt with reference to a saturated calomel electrode. Although a good (but lesser) degree of protection was noted at potentials more noble than —0.77 volt, this degree of protection could not be obtained at lower current densities. Therefore, —0.77 volt was considered to be the optimum protective potential.

It was found that the applied currents indicated by the breaks in cathodic polarization curves agreed reasonably well with the currents required to maintain polarization at —0.77 volt. The break current, which also was observed to be related to the corrosion current itself, is therefore considered to be a good measure of the current required for optimum protection. In some of the experiments, a short preliminary period of exposure without protective current greatly reduced the amount of current initially required for cathodic protection.

1. Current and Potential Relations for the Cathodic Protection of Steel in Salt Water. By W. J. Schwerdtfeger. *J. Research NBS*, **60**, No. 3 (1958) RP 2833.
2. Potential and Current Requirements for the Cathodic Protection of Steel in Soils. By W. J. Schwerdtfeger and O. N. McDorman. *J. Research NBS*, **47**, 104 (1951) RP 2233.

BOOK NEWS

Bulletin of The India Section, The Electrochemical Society. 30 pages, 7¼ 9¾ inches. The Electrochemical Society, Indian Institute of Science, Bangalore 3, India. Price not indicated.

The issue examined was Vol. 7, No. 1, January, 1958. Included in the contents was a paper "Vapour Phase Corrosion Inhibitors, Part I: Different Types and Performance" by K. S. Rajagopalan. An editorial, after commenting on the increasing interest in corrosion control being evidenced in India points to several papers published on the subject, a symposium on electrodeposition and metal finishing, discussion of rare metals and a symposium on corrosion of metals arranged by the India Science Congress.

Wear. 6½ x 9½ inches. Elsevier Publishing Co., Spuistraat 112, Amsterdam-C, The Netherlands. Per 500-page Volume, $15.00.

Received were August, October and December, 1957 and February, 1958 issues, being Issues 1-4 inclusive, Volume 1. The magazine, identified as an "International Journal on Fundamental of Friction, Lubrication, Wear and Their Control In Industry," lists an editorial and advisory board consisting of members from Scotland, Australia, England, Russia, United States, India, Germany, Holland, Switzerland, Italy, Denmark and Japan.

The publication is intended to cover frictional and mechanical damage due to wear, testing, wear prevention, statistics and other aspects of the wear problem. Articles in German and English appear in the first issues.

Also included are sections on abstracts (in English); bibliographies, recent events, coming events and notes on contributions. Battelle Review's Systematic Abstracts of Current Literature are being reprinted.

ASTM Standards on Light Metals and Alloys. 306 pages, 6 x 9 inches, paper. December, 1957. American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa. Per copy, Non-Members ASTM, $3.75.

Covers aluminum and its alloys, cast and wrought magnesium and magnesium alloys, cast and wrought methods of testing, light metals. The volume consists of the collected standards and tentatives in the light metal field prepared by Committees B-7 on light metals and alloys; B-6 on die castings; B-1 on aluminum wire and cable; E-1 on methods of testing and E-3 on chemical analysis.

Attenuation of Gamma Rays and Neutrons in Reactor Shields. By Herbert Goldstein, Nuclear Development Corp. of America. 295 pages, paper. Superintendent of Documents, U.S. Government Printing Office, Washington, 25 D.C. Per copy, $2.

A thorough exposition of the fundamentals involved in shielding against neutron and gamma radiation. Calculation methods on attenuation of neutrons and gamma rays.

PERIODICALS

Tetsu-To-Hagane Abstracts No. 5. (Abstracts from the Journal of the Iron and Steel Institute of Japan.) In English. 78 pages, 7¼ x 10¼ inches, paper. Dec. 1957. The Iron and Steel Institute of Japan, Naga-14-go-kan, Marunouchi-2-chome, Chiyodaku, Tokyo, Japan. Per copy, $1.

The abstracts cover the publications of the journal during 1955. Abstracts consider such topics as ferrous materials, refractories, manufacture of pig iron, steel making, casting of iron and steel, fabrication, properties and physical metallurgy, chemical analysis, reviews and miscellaneous. One paper considers effects of silicon and carbon on the corrosion resistance of acid resistant high silicon iron.

Equipment Services NEW PRODUCTS Materials Literature

Aluminum

Aluminum-Lithium alloy, designated X2020, developed by the Air Research and Testing Committee and the Aluminum Company of America, is lighter than conventional alloys but has substantially higher elastic modulus. It will permit operations at up to 400 F, some 100 degrees higher than conventional alloys.

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Aluminum Company of America, (743) Alcoa Bldg., Pittsburgh 19, Pa., has developed a new sheet alloy processing bright finish and superior stain resisting properties. Present use is in the manufacture of cooking utensils, jewelry, optical frames, appliance trim and other products calling for a lustrous, enduring finish.

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Alcoa Fabricating Facilities is the title of a new 14-page booklet pictorially describing the engineering services and complete array of metalworking tools available in Aluminum Company of America's jobbing facilities. Alcoa, 1501 Alcoa Bldg., Pittsburgh, Pa.

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Ormet Corp., producers of aluminum, has opened a new plant, which under full production will produce 180,000 tons of primary aluminum annually. The firm is co-owned by Olin Mathieson Chemical Corp. and Revere Copper and Brass, Inc. The plant is located between Clarington and Hannibal, Ohio, on the Ohio river.

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Gulton Industries, Inc., Metuchen, N. J., manufactures an aluminum welder which welds with high frequency sound vibrations. Thin sheet aluminum can be welded for air tight packaging of foods and other substances. Use of the ultrasonic welder for joining electrical connections is projected.

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United States Steel Corp. plans to enter the aluminum coated steel sheet market. Commercial production of USS aluminum coated sheets will follow a facility modification program at the Irvin Works near Dravosburg, Pa.

Anodes

Corrosion Services Incorporated, P. O. Box 7343, Tulsa, Okla., has published a pamphlet, "The Truth About the Current efficiency of the Galvomag Anode," giving comparative test data to show only a negligible difference in current efficiency between Galvomag and another type of anode. Principal asset of Galvomag, the pamphlet says, is its high potential.

Cleaning

Ultrasonic Cleaning, a new illustrated booklet based on 12 years of experience in the field, is now available from Branson Ultrasonic Corp., 40 Brown House Rd., Stamford, Conn. The 24-page Bulletin S-200 explains practical applications and basic principles of this modern cleaning method as well as design of equipment. Speed, thoroughness, and ability to clean intricate parts without dismantling them are assets of the process.

Coatings—Organic

IFCO Catalytic, Industrial Finishes Company's catalytic coating can be used as a chemical treatment, rust-inhibitive coating and a primer for top coat systems according to the manufacturers. In 200-hour salt spray U. S. Government test, relative humidity 99 percent and 95 F for 1500 hours the coating showed no deterioration. The coatings, as used by Radio Corporation of America, were found to be oil resistant, alkali, acid and heat resistant. They may be applied to almost all metals, wood, glass and concrete. They cannot be used as a primer coat where a nitrocellulose or acrylic lacquer top coat is to be used. Any other system of painting is suitable. More information is available by writing Industrial Finishes Co., Inc., 1119 Land Title Bldg., Broad & Chestnut Sts., Philadelphia 10, Pa.

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Charcote CIC-21, made by the Charleston Rubber Co., Stark Industrial Park, Charleston, S. C., is a liquid Neoprene protective coating with a "built-in" primer. Outstanding qualities are its ease and flexibility of application, excellent long lasting resistance to weathering, chemical fumes, salt spray and corrosion creep, and very good resistance to impact and abrasion.

•

Minnesota Mining and Manufacturing Co., 900 Bush Avenue, St. Paul, Minn. is making available for the first time, two latex forms of a fully-saturated halofluorocarbon rubber intended for industrial application requiring extreme resistance to corrosive chemicals and heat. Until now the copolymers of chlorotrifluoroethylene and vinylidene fluoride made by the 3M Chemical Products Group and known as "Kel-F" brand elastomers have been available only in gum or resin form.

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J. Landau & Co., Carlstadt, N. J. has organized a special finishes research division.

Coatings—Metallic

Nowery J. Smith Co., Houston, Tex., is operating a hot-dip zinc galvanizing kettle measuring 32 feet, 6 inches long, 5 feet, 4 inches deep and 4 feet, 2 inches wide. Structural steel beams up to 63 feet long can be galvanized by double-dipping. The company also offers other corrosion preventive processes including metallizing, pickling and oiling and prime-coating and painting.

Ditch Padder

Crutcher-Rolfs-Cummings ditch padding machine which screens and uses soil dug from the ditch as padding for the pipe is being marketed. Rocks and particles too large to go through the moving screen are carried off to the side. The screen is in the form of an endless steel wire grid, rotating on a shaker track system.

Electrical Motors

Climatized Vertical Hollow Shaft motor made by the Louis Allis Co., 427 E. Stewart St., Milwaukee 1, Wis. can be used both indoors and outdoors without protection. Recent advances in insulating materials provide optimum resistance to moisture and chemical contaminants, company spokesmen say.

Engineering

Evidence of an increasingly worldwide awareness that corrosion losses can be drastically reduced is contained in a report of global corrosion work being done by **Ebasco Services, Inc.,** New York, N. Y. Two U. S. Navy seaplane ramps in Bermuda; a 2000-foot pier at the Free Port of Monrovia, Africa, where the above water portion of steel piers, already partially rusted, is protected by encasement with reinforced concrete; an entire corrosion protection system for extensive U. S. Army installations on Okinawa and three pipeline contracts in the United States are keeping the company's corrosion engineers busy.

Fittings

Babcock & Wilcox Co., 161 E. 42nd St., New York, N. Y. has published a new folder which explains how money and time can be saved by ordering fittings and flanges which are produced to close dimensional tolerances. Bulletin FB-504 can be obtained by writing the sales office, Beaver Falls, Pa.

Heat Exchangers

Thermek, Bi-Metal extended surface heat exchangers are made with 5/8-inch OD, 18-gauge stainless steel tubes over which a 12-inch SPS aluminum tubes spined with radial spines are shrunk. The radial spines give high capacity, manufacturers, Heatron, Inc., York, Pa. say.

Inhibitors

Archer-Daniels-Midland Company, 700 Investors Building, Minneapolis 2, Minn., has begun semi-commercial production of primary aliphatic amines, fatty nitrogen compounds with many industrial and chemical applications. George Nelson, ADM director of development said the materials are the first of a series of fatty nitrogen chemicals which ADM will produce. The fatty amines are used for corrosion inhibition, surface active agents, ore flotation, rubber compounding, textile auxiliaries and chemical intermediates.

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NEW PRODUCTS

(Continued From Page 83)

Instruments

National Cylinder Gas Co., is marketer of the first electronic line tracer for flame shape-cutting machines in the United States. The device was developed for NCG by Canadian Westinghouse Company, Ltd. The instrument is an adaptation of newly-developed optical "sensing" systems. It steers metal-cutting torches by scanning or "reading" ordinary pen or pencil line drawings. Savings in costs of pattern preparation are significant, spokesmen say.

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The Ultrasonic Flaw Plotter for inspect castings and forgings of armor plate is said by the manufacturers, Alcar Instruments Inc., Little Ferry, N. J. to be among the firm's most important developments. Alcar Instruments was recently acquired by Narda Ultrasonics Corp., Mineola, L. I. Alcar will be operated as an independent subsidiary.

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The W-2 Wilkinson Line Locator is a newly developed compact, highly effective electronic locating instrument for all subsurface metallic structures, the makers, Wilkinson Products Co., say. Lightness, compactness and trouble-free service are features stressed by the manfacturer. For more information write the company at 3987 Chevy Chase Drive, Pasadena 3, California.

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Unit Process Assemblies, Inc., 61 West 4th St., New York 3, N. Y. has developed a right angle probe for testing most coatings and films on the inside diameters of pipes, bores in castings and other parts with internal diameters of as small as one-half inch, with special probes being able to test even smaller diameters. Using the Dermitron instrument, only two seconds are required to test coating thickness. The probe operates on eddy-current principles.

Gardiner Electronics Co., 2545 E. Indian School Road, Phoenix, Ariz., has developed a new transistor pipe locator and metal detector with a maximum range of 21 feet. It uses eight transistors, one in the transmitter, seven in the receiver. It has four flashlight batteries, two in the receiver which last 3000 hours and two in the transmitter which last 350.

Laboratories

E. I. du Pont de Nemours and Company, Inc., Wilmington 98, Delaware has opened a new $5,000,000 laboratory which will provide service to customers and evaluate new or improved products of the du Pont Company's electrochemicals and pigments departments. The laboratory contains 81,000 square feet of floor space, including 150 separate rooms, laboratories and demonstration areas. There are 130 technical trained staff members.

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Stoner Mudge Co., a division of American-Marietta Co., Pittsburgh, has more than doubled its laboratory facilities, providing a total working area of almost 14,000 square feet. The firm produces all kinds of coatings for the container, paper, appliance, automotive, textile, metalworking and plastic industries.

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Nicolet Industries, Inc. has opened a research and development center at Florham Park, N. J. for control and testing of its own and other products. Modiglass Fibers, Inc. a Nicolet component, also will be located at the center.

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Gordon and Campbell, Consulting Chemists, 12 Brookfield Way, Morristown, N. J. specialize in application of thermoanalytical research techniques to industrial problems. Saul Gordon and Clement Campbell are the principals.

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Temco Aircraft Corp. will add 52,000 square feet to its Garland engineering center in connection with its new activities as a prime contractor for missiles, aircraft and electronic systems. The center will have over 150,000 feet of floor space.

Metals—Ferrous

Lukens Nine Nickel, an alloy plate with high impact resistance and high strength at temperatures as low as —320 F is available from Lukens Steel Company, at prices about one-half the cost of other materials used in low temperature service. It has a minimum tensile strength of 90,000 psi and minimum yield of 60,000 psi.

•

The Bell Telephone Co. uses stainless steel pole line hardware in extremely corrosive environments. Wire, crossarms, and auxiliary equipment are made of stainless steel instead of the usual hot dip galvanized carbon steel normally used. The company calculates life of the stainless steel will equal that of galvanized carbon steel used in normal corrosive atmospheres.

Metals—Non-Ferrous

Bart Manufacturing Corp., Belleville, N. J. has enlarged its facilities for the nickel cladding of steel plate, sheet, heads and fabricated shapes by the "Bart Lectro-Clad" process. Facilities are now available for nickel cladding steel heads up to 132 inches diameter by 36 inches deep, sheet and plate 89 inches by 246 inches and 132 inches by 132 inches, and shapes up to 60 inches by 144 inches.

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Titanium Welding, a 31-page bulletin published by Titanium Metals Corp. of America describes and illustrates various welding techniques. Fusion welding equipment and procedures, resistance welding and evaluating weld quality are all considered. Various weldments typical of different welding techniques required are pictured and explained. For more information write for Bulletin 6, Titanium Metals Corporation of America, 233 Broadway, New York 7, N. Y.

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Anadite, Inc., 10630 Sessler St., South Gate, Cal. recently produced the first chemical milling on titanium for missiles. The parts processed were titanium spheres made by Rheem Corp. and used to help control propellant flow into the combustion chambers of the Atlas ICBM.

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Inconel 702 and Incoloy T, wire, rod and strip usable respectively at temperatures up to 2400 and 1700 F are being produced by Techalloy Co., Inc., Rahns, Pa.

Plants

Ladish Co., Cudahy, Wis. has opened a new manufacturing plant, sales service office and warehousing facilities in Houston, Texas at 1301 West Belt Drive, North. The Texas division will serve the area with pipe fittings, corrosion resistant valves, saw blades, drop forgings and rolled rings.

(Continued on Page 86)

FUTURE

"The best preparation for the future
is the present well seen to,
the last duty done."

—George MacDonald

While long-range planning is of great importance to the development of any company, it can prove entirely futile unless it is based upon the solid foundation of conscientious day-to-day achievement.

For it is the accumulation of single actions that determines a company's reputation. And a good reputation for superior performance is the best insurance for a bright future.

This is the premise upon which Mayes Bros. has built a 28-year reputation for quality craftsmanship, using quality materials, in pipe coating and wrapping. Every Mayes' job is and has been an important job performed with maximum efficiency to assure permanence under the most savage assaults of subsurface corrosion forces.

Thus, we plan for our future today — in large part by insisting on doing the best job possible today and every day.

1150 McCarty Drive

MAYES BROS.

HOUSTON, TEXAS

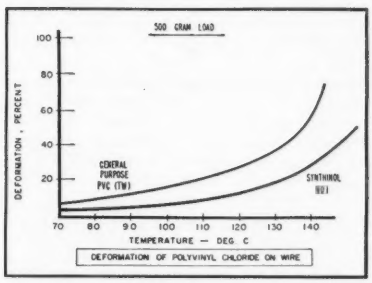
Tel. ORchard 2-7566

Troubled with wiring failures in your refinery?

If so, consider the record being established by Rome Synthinol 901, a special 90° PVC compound for wire insulation and sheathing. It has helped to solve an impressive list of difficult wiring problems.

Developed by Rome Cable's laboratory and first introduced in 1949, Rome Synthinol 901 has proved by test and actual use to be superior to conventional PVC compounds in the following ways:

a. Suitable for continuous operation at higher temperature (90°C).
b. More stable under severe heat cycling.
c. Suitable for continuous immersion in hot transformer oil.
d. Superior resistance to chemicals and solvents.
e. Greater resistance to heat deformation.



Graph shows heat deformation vs. temperature, and compares Synthinol 901 with conventional PVC compounds. Test run in accordance with Underwriters' Laboratories standard procedure, except for temperature.

The practical value of this compound can best be illustrated by describing a number of actual case histories.

(1) Oil refinery, industrial and chemical plant wiring.

Plant and oil refinery engineers have long used conventional PVC insulations for plant wiring with good results, but too often heat deformation problems arose in warm locations. Since Rome Synthinol 901's superior deformation resistance suggested that it might be the answer to this problem, it was tried and soon became widely used because of its much better service record.

Synthinol 901 also proved to be far superior to conventional materials for chemical plant wiring where the corrosive action of chemicals and solvents has always been a tough problem. Although polyvinyl chlorides as a class have inherently better resistance to chemicals and solvents than many other materials, some engineers desired even further improvement. One user decided to test a number of samples over a long period by immersing them in various concentrations of acetone, different alkalis, and butyric, propionic, and acetic acids. The results of this careful evaluation showed clearly that, when exposed to these chemicals, Synthinol 901 would last longer than any other PVC tested.

(2) Oil-filled transformers.

Transformer engineers have long sought a cable construction to replace varnished cambric-insulated cable for leads in oil-filled transformers. These leads connect transformer windings and bushings and are constantly immersed in hot oil. One transformer manufacturer, encouraged by successful experience with Synthinol 901 on other applications, undertook a comprehensive study of the possible usefulness of this insulation in lieu of varnished cambric for high-voltage transformer leads. This study extended over a several-year period and proved to those engineers involved that there were at least four reasons for standardizing on Synthinol 901 for this application:

a. There was less sludge in the oil than when VC insulation was used.
b. There was no harmful degradation of the electrical properties of the oil.
c. Conductors insulated with Synthinol 901 ran cooler, permitting a 7% increase in lead cable current rating.
d. The use of Synthinol 901 in lieu of VC would permit substantial dollar savings.

(3) Coil leads.

Many manufacturers of small coils for relays, small transformers, small motors, and electronic components have tried to use PVC insulated lead wires for many years. Typically, these leads are crimped or soldered to the ends of the coil; and the whole coil is then impregnated with varnish or wax and baked as long as 16 hours at temperatures as high as 150° C. The varnish used may be asphaltic, phenolic, alkyd, etc.; and the wax may be paraffin, beeswax, carnauba, or another kind.

PVC insulated lead wires frequently produced serious production problems because of the insulation's tendency to shrink, crack, and stiffen during the impregnation and subsequent baking period. Synthinol 901 was substituted in place of the ordinary PVC insulation and, after nearly eight years of wide usage, not a single case of shrinkage, cracking, or stiffening of insulation involving Synthinol 901 has been brought to our attention.

These case histories describe just a few of the applications for which Rome's Synthinol 901 has proved especially effective. Perhaps they will suggest other applications in your own area which might also be better handled with Rome Synthinol 901 instead of a conventional PVC compound. If you have a wire or cable problem that might be solved with Rome Synthinol 901, why don't you get in touch with us? Contact your nearest Rome Cable representative for more information—or write to Department 320, Rome Cable Corporation, Rome, N. Y.

ROME CABLE
CORPORATION

NEW PRODUCTS

(Continued From Page 84)

Plastics

Plaskon Laminating Varnish V-204, a new phenolic laminating resin developed by Barrett Division, Allied Chemical Corp., retains its high strength at 500 to 600 F. Its strength is said to exceed that of the chief competitive phenolic formerly utilized in fabrication of lightweight radomes, missile heads and complex-shaped structural aircraft parts.

•

Munray Products Co., Cleveland, Ohio is marketing a new transparent polyvinyl chloride tubing. The flexible tubing, LT 310 is recommended for general laboratory use and for conveying foods and liquids where a slight imparted taste is unobjectionable. Tiny air bubbles, or very small impurities can be seen through the clear tubing. It is resistant to weak acids and alkalies, will handle light slurries. Operating temperatures range up to 175 F.

Pumps

Ampco Metal, Inc., 1745 South 38th St., Milwaukee 46, Wis., have recently added a 1-inch (suction) by ¾-inch (discharge) 316 stainless steel pump to its line. Some features are, a one-piece sleeve and impeller to eliminate shaft wear and corrosion attack without gaskets; a corrosion-resistant drip basin as an integral part of the casing; and an alloy splash plate which covers and protects the motor or pedestal.

Valves

Cooper Alloy Corp., Hillside, N. J., makes stainless steel renewable disc "Y" valves useful in handling corrosive chemicals, petroleum products, spirits, gases and slurries. The valves have renewable discs and an extra lift to remove the disc from the flow area and minimize line entrapment and pressure drop.

Wood

Synthetic Wood has been produced in the laboratory of Battelle Memorial Institute, Columbus, Ohio. The material soon may supplement the nation's natural lumber supply. The new substance was developed from a Portland cement-based material that has many of the desirable properties of wood for the Wells Manufacturing Co., South Bend, Ind. It can be sawed, nailed, glued, and worked with woodworking tools.

PROVED BY MILES & MILES & MILES &

MEN in the NEWS

(Continued From Page 86)

lurgy to receive the Rosenhain Medal for 1958 given by the Institute of Metals in London, England.

•

Paul W. Steen has been appointed manager of distributor sales for the Narda Ultrasonics Corp., Mineola, N. Y. He is a BBA graduate of New York university, and has studied electrical engineering at Adelphia college. He has both a technical and administrative work-background, having been an electronics instructor and an advertising manager.

•

Gerald L. Moran has been appointed vice president of the chemical and metallurgical division of Sylvania Electric Products, Inc. Mr. Moran will have over-all responsibility for the firm's chemical and metallurgical division, parts division, and Sylvania Home Electronics, a Sylvania division.

•

Robert S. Owens was recently elected to the board of directors of Nicolet Industries, Inc. Mr. Owens is also a director of John Wood Industries, Ltd. and vice president and treasurer of two subsidiary companies. Nicolet Industries, Inc. produces asbestos papers and boards, pipe coverings, sheets and blocks, asbestos pipe wraps and other like materials.

•

Richard F. Hurley is the newly appointed technical sales representative for the metal working chemicals division of the American Chemical Paint Co., Ambler, Pa. He will have offices in St. Joseph, Mo. and will cover Iowa, Minnesota, North and South Dakota, Colorado and Nebraska.

•

John I. Rudge was recently elected a vice president of Carlon Products Corp., Cleveland, Ohio. He will be responsible for the Southeastern district. Mr. Rudge has headquarters in Asheville, N. C. where the Carlon plant makes plastic pipe. In April, the firm began manufacture of a new plastic pipe, Carlon "D" for sewer and drain use. The firm also manufactures Kralastic, PVC, and polyethylene fittings.

•

P. B. Mayfield was elected president of the American Wood Preservers' Association at the association's annual convention in Los Angeles, April 14-16. Mr. Mayfield, Barrett Division, Allied Chemical & Dye Corp., has been associated with the wood preserving industry for 32 years, starting with a wood preserving company right after graduation from college. He joined Barrett Division as technical consultant on wood preservatives and industrial pitch in 1949 and is now manager of industrial tar products sales.

•

G. L. Erickson is now technical supervisor, industrial tar products sales of Barrett Division, Allied Chemical Corp., New York. Mr. Erickson joined Barrett in 1954. Prior to this he operated his own commercial testing and consulting laboratory, and was a chemist with the Texas Company.

•

Gustav O. Hoglund has been elected president of the American Welding

(Continued on Page 88)

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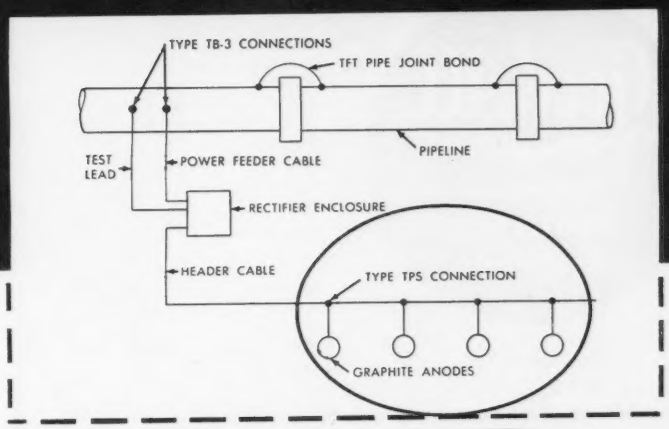
reduces cost on header cable connections



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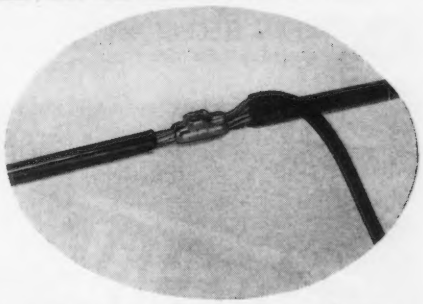

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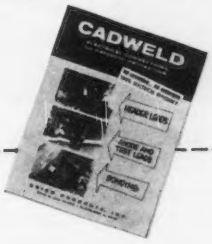

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MEN in the NEWS

(Continued From 87)

Society. Mr. Hoglund is head of the welding section of the Aluminum Company of America Process Development Laboratory. He has been with the firm since 1928.

•

Frederick F. Wood has been elected assistant to the vice president (publicity and advertising), **Dr. Vladimir Hospadaruk** has joined the staff of the research laboratory at Bayonne, N. J. and **Marcel A. Cordovi** has joined the staff of the atomic power developments section of the development and research division International Nickel Co., Inc.

Mr. Wood has supervised the company's corporate advertising and industrial publicity since 1947, and directed its motion picture activities since August, 1950. He will oversee and be responsible for co-ordinating all publicity and advertising activities for the company and subsidiaries.

Mr. Hospadaruk is author of several papers in the field of electrochemistry. He is an honor graduate of McGill university, Montreal, and holds a PhD in electrochemistry from that school. He has both a teaching and industrial background.

Mr. Cordovi, prior to his association with International Nickel, served as manager of the materials and testing department of the atomic energy division of the Babcock and Wilcox Co. Since 1950, he also has been a consultant in metallurgical engineering at the Brookhaven National Laboratory of the Atomic Energy Commission at Upton, N. Y. and an adjunct professor of metallurgical engineering at the Polytechnic Institute of Brooklyn.

•

Dr. Robert F. Mehl, Carnegie Institute of Technology, was one of 30 men elected to membership in the National Academy of Sciences, Washington, D. C. April 29. Mr. Mehl was cited for "distinguished achievements in original research." The National Academy is a private organization chartered by Congress during the presidency of Abraham Lincoln for the furtherance of science and its use for the general welfare. It is required by its charter to advise the government in scientific matters.

•

George H. Bills has been named Chicago regional sales representative for the Johns-Manville Dutch Brand Division. The firm makes industrial tapes, adhesives and rubber products.

•

Dolores Ombres has been named supervisor of chemical service laboratories in the chemical research and development department of Hagan Chemicals & Controls, Inc., Pittsburgh, Pa. Much of her duty is in the firm's laboratories division working on industrial water consultation.

•

Salvatore Piccione has joined the research and development department of Pittsburgh Coke & Chemical Co. A physical chemist, he will be assigned to the analytical and physical research section of the laboratory.

•

John M. Thomas has resigned as vice president of H. C. Price Co. in order to devote more time to his personal affairs, particularly his cattle ranch near Bartlesville, Okla.

•

Lew B. Phillips has been appointed district manager, gas industry sales for the Great Plains States with headquarters in Kansas City, Missouri. The firm is one of the Dresser Industries, Inc., Bradford, Pa.

•

Vsevolod N. Krivobok, well-known authority on stainless steels and supervisor of the stainless steel and heat-resistant alloy section of the development and research division of the International Nickel Co., Inc., died May 17. He was a graduate of St. Petersburg, Russia, Polytechnic Institute and of Harvard University.

•

William Blum, noted scientist of Washington, D. C. won the first annual Scientific Achievement Award given by the American Electroplaters' Society. From 1913 to his retirement in 1951, he was head of the electrodeposition section of the National Bureau of Standards. He has been a consultant since his retirement.

•

Irl C. Schoonover has been appointed acting associate director for planning at the National Bureau of Standards. He succeeds N. E. Golovin who has been appointed chief scientist of the Army's White Sands Missile Range. Mr. Schoonover will continue as chief of the mineral products division.

•

Quandt M. Adams has been named senior technical man at the new B. F. Goodrich Chemical Co., glacial acrylic acid plant in Calvert City, Kentucky. He previously worked on the development of the acrylic acid process at the company's development center, Avon Lake, Ohio.

•

Kenneth W. Donle has been appointed chief engineer of the Tube Reducing Corp. In his new post he will direct all engineering activities. Tube Reducing manufactures cylinder-finish seamless steel tubing, compression-formed tubing and the "Niphos" process corrosion-resistant coating.

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How to Make a "Corrosion Motor"★

A SIMPLE machine will demonstrate how the power generated by the corrosion of two metals of similar composition but differing physically on their surfaces will operate an electric motor. Rusty aged iron pipe and clean bright iron pipe when immersed in a solution will produce power sufficient for this purpose.

The reaction is like that occurring when dissimilar metals, such as copper and iron, galvanized iron and copper or a combination of all three materials plus brass are coupled in an electrolyte. Home plumbing systems are an example of this type of assembly commonly encountered.

Potential differences between metallic structures in solution have been tabulated by many investigators and may be found in nearly all books on corrosion. The result of combining galvanized iron pipe and copper tubing often observed in the home will be obvious in this presentation.

Characteristics of the solution in which metals are immersed, that is any aqueous mixture, are important in the corrosion reaction. The solution may be a brackish salt marsh or moist garden soil that has been fertilized. Humidity in the air above the water in a storage tank may be high enough to make a conductor for electrical current.

pH Is Index of Corrosivity

The pH factor or index of relative acidity of the solution is an indirect index to the hydrogen-iron activity or corrosivity of the materials involved. Generally speaking, as the pH number decreases the corrosivity increases, that is, a soil or solution is more corrosive if it is "sour" than if it is "sweet". This is the basis of the internal corrosion control used by the City of San Diego in its distribution pipe line system. About 16 tons of calcium carbonate is used during an average summer day at the Alvardo Filtration Plant to help purify and control the pH of the water.

The amount of electrical power developed by a simple cell with short lengths of pipe can be shown readily. Both soil and tap water may be used to simulate actual conditions. Approximately six inches each of 1-inch copper, galvanized and black iron pipe are used with elbows and nipples to demonstrate how much power is developed by corrosion of simple plumbing connections.

★A version or a discussion prepared by R. C. Tullis, San Diego, Cal. and presented and displayed by him during Engineering Week at San Diego in February, 1958, at the American Water Works Association Conventions in 1956 and 1957. He has described the "corrosion motor" before numerous groups and finds it helpful in explaining the electrochemical nature of the corrosion process.

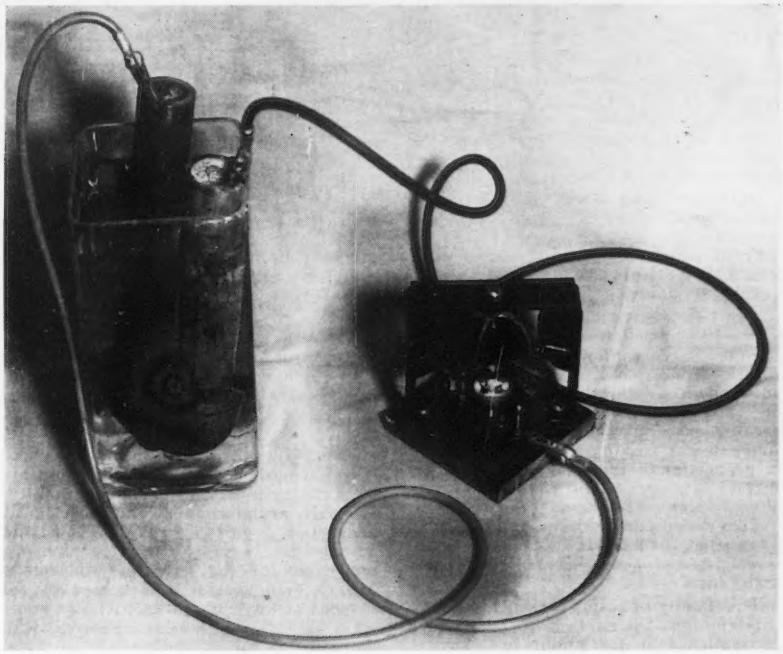

Figure 1—In this model of the "corrosion motor" at 0.50 volt terminal voltage and 0.001 ampere current, the armature will rotate at 60 rpm. It develops about one-half "flea power". Power cell on the left consists of brass and black iron pipe segments connected with appropriate elbows and an insulating nipple at the bottom. Electrolyte is tap water. The fast shutter of the camera "stopped" the rotating armature in this photograph.

Mud, Distilled Water Used

A cell that may be used for this demonstration is composed by a 6-inch length of 1-inch black iron pipe with scale and grease removed and a 6-inch length of clean copper 1-inch tubing. These are joined at the bottom with appropriate elbows and a nipple. This bit of plumbing is immersed in a "soupy" mixture of distilled water and tidal mud which has a pH of 5 at the start of the experiment. By most standards, this soil is termed "very corrosive."

Another cell can be composed of 6-inch lengths each of 1-inch galvanized iron pipe and 1-inch black iron pipe that has been thoroughly cleaned. This unit is made up in the same manner as the first cell and is immersed in a solution of distilled water and sandstone-clay soil from Chollas Station, San Diego. This solution has a pH of 6 and is termed "quite corrosive" by present standards.

Another possible cell is a 6-inch length of 1-inch brass pipe and a 6-inch length of 1-inch black iron pipe that is thoroughly cleaned. A glass jar is filled with San Diego City tap water adjusted at the filter plant to a pH of 8.8.

Motor of Light Construction

The motor is of light construction similar in principle to the D'arsonval moving coil meter. Alnico V field magnets provide a strong, stable, magnetic field. The moving coil or rotor is large enough to be easily seen. The number of ampere turns of wire in the rotor is calculated to provide maximum torque with the minimum voltage available, that is, the zinc-iron cell voltage of .38 volts. At this voltage, the motor draws 1.5 milliamperes of current resulting in .00057 watts consumed by the motor. This may be compared to about one-half flea power. See the cell and motor arrangement in Figure 1.

When wires from the exposed ends of the pipes are connected to the poles of the motor, the rotor moves. It will continue to move as long as the corrosion of the metals continues, proving that corrosion is an electrical phenomenon.

The zinc-iron cell used in this experiment can develop up to one-half ampere for short periods under ideal conditions. Using an average home plumbing installation as an example, one-tenth horsepower may be generated by the dissimilar metals coupled in the yard. These may be considered as long line currents, local cell currents or both and they are produced by differences in soil structure, differential aeration and differences of the surface composition of the metals involved. These combinations may generate currents far in excess of the galvanic couple currents developed in this demonstration.

Some Physical and Chemical Properties Of Aromatic Polycarbonate Resins*

Abstract

Some of the physical and chemical characteristics of a new family of aromatic polycarbonate resins are given. The polymers are useful in many corrosive environments, including hydrocarbons of various kinds, sulfuric acid, hydrofluoric acid and hydrochloric acid. Data are given on Izod values, tensile-impact tests, water absorption, heat distortion resistance, electrical properties. Some results of tests in various environments are given. 6.6.8

THE PHYSICAL and chemical properties of the first member of a new family* of plastic materials which is approaching commercial stages is described herein. Properties and results of tests of prime interest to people seeking new materials to resist corrosion are emphasized.

In the new and novel field of aromatic polycarbonate resins, the polycarbonate resins are characterized by simple chemistry in which bifunctional phenols are joined together through a carbonate linkage as shown in Figure 1.

The bifunctional phenol. Bisphenol-A, which is available in suitable purity commercially, combines with carbonyl chloride (phosgene) to give the polymer unit shown. Obviously, the R group can be varied and substitutes put in the various free positions on the phenyl rings to get an almost infinite variation in properties of the final polymer. Further, too, copolymers of various bisphenols and of bisphenols and other dihydroxy compounds can be made and have been made. They form a very interesting and versatile family of new materials.

This family of resins presents a unique combination of strength properties which recommends it for applications where strength and toughness are needed.

The notched Izod values run about 12-16 ft lb per inch of notch. The unnotched Izod values are somewhere in the region greater than 70 ft lb per inch. It has proved impossible to break an unnotched Izod sample ¼-inch wide even when using a 16 ft lb hammer. The samples stretch and bend but do not break.

The tensile-impact strength test is about three years old. In this test the sample in the form of a tensile bar is held horizontally and is clamped at one end so that the impact pendulum pulls the sample at the free end to cause a tensile stress. The tensile impact values are said to correlate much more closely to service conditions than the notched Izod values.

In Figure 2 the notched Izod values are on the left-hand scale and the tensile-impact values on the right-hand scale for the polymer as compared with four other general purpose plastic materials.

Temperature Reaction Tested

Until recently the temperature of boiling water was too great for most thermoplastics because at that temperature they would soften, unmold and distort. Temperature tests on the new resin are made with a bar ½ x ½-inch in cross section by 5 inches long mounted on supports 4 inches apart and subjected to a load such that a tensile fiber stress of 264 psi is developed. A stress of 66 psi is also used to indicate the sensitivity of plastics to load variation in this test.

In Figure 3 the heat distortion point in degrees F for the resin is compared with three other thermoplastics and with phenolic thermosetting resin. The new thermoplastic resin has practically the same heat distortion temperature as the thermosetting resins.

Low water absorption in molded parts is important because moisture often affects dimensional and chemical stability, as well as mechanical and electrical properties. Figure 4 gives details on the amount and rapidity of moisture pickup on pellets of the new material about ⅛-inch diameter by ⅛-inch long. At 50 percent relative humidity at room temperature, the maximum of 0.15 percent moisture absorption is reached in about 4-5 days. When immersed in water at room temperature, the pellets pick up a maximum of 0.35 percent water in about 5-6 days. In boiling water, the maximum absorption of 0.58 percent is rapidly attained in about one day.

The data on Figure 5 were collected after 24 hours' immersion in water at room temperature. Except for polystyrene, the new resin's water absorption of about 0.3 percent is lowest.

Dimensional Stability Good

Molded parts have exhibited excellent dimensional stability under a wide variety of conditions. Some of the conditions studied are given on Table 1 along with the average dimensional change in thousands of an inch per inch. Interesting to oil people is the excellent dimensional stability in hot oil on the last line.

Table 2 gives values for tensile, flexural and compressive strength and the respective modulus for each. A study of tensile strength vs temperature indicates that from —30 C (86 F) to +135 C (275 F), there is a linear relation between tensile strength and tempera-

(Continued on Page 92)

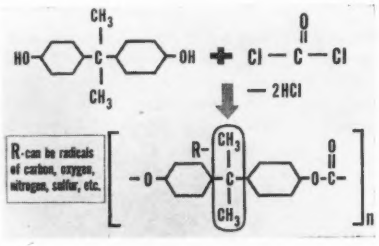

Figure 1—Chemistry.

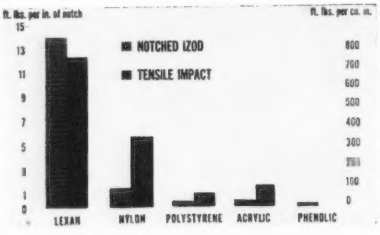

Figure 2—Comparative impact strength.

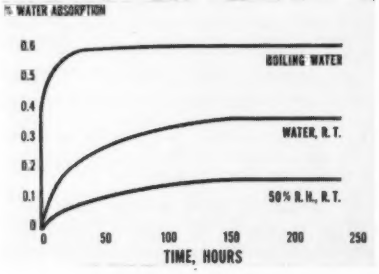

Figure 4—Water absorption.

TABLE 1—Dimensional Stability

	Average Dimensional Change (mils per in.)
30 days at 70°C (160°F)	0
90 days at 125°C (257°F)	—1
24 hours in water at RT	0
4 days at 100% RH at 100°F	0
7 days in oil at 160°F	0

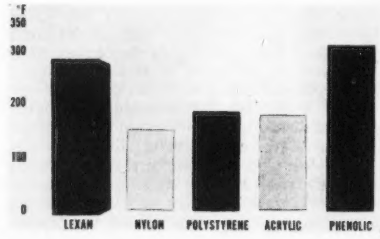

Figure 3—Compartive heat distortion point (Degrees F at 264 psi).

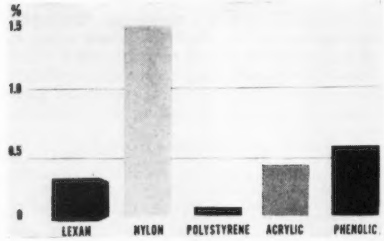

Figure 5—Water absorption (24 hours at room temperature).

★ Extracted from a paper "Aromatic Polycarbonate Resins: New Rugged Plastics," by K. B. Goldblum, Supervisor Development Unit, New Product Development Laboratory, General Electric Company, Pittsfield, Mass. Presented at the University of Oklahoma Short Course on Corrosion, Norman, Okla., April 1-3, 1958.

* Lexan, a trade-name of General Electric Company for the polycarbonate resins.

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4287 Abstracts on Corrosion Arranged By Subject Matter

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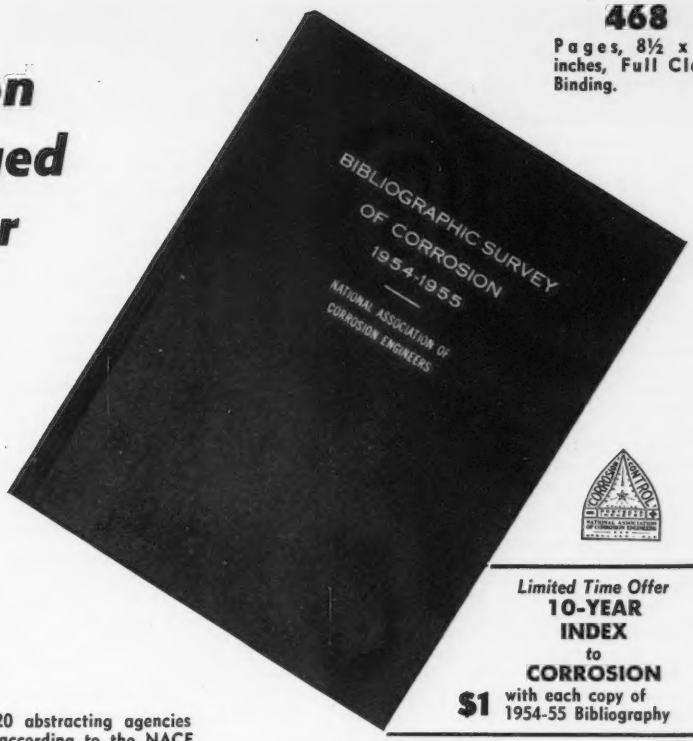

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Some Physical—

(Continued From Page 90)

ture. The slope of this line is about —50 psi per degree C.

The tensile strength is about 9000 psi at room temperature; about 12,400 psi at —30 C; and about 3500 psi at 135 C.

The new resin has a fine combination of electrical properties some of which are indicated in Figure 6. Note the low 60-cycle power factor and the high volume resistivity and low arc resistance. This latter is characteristic of thermosetting phenolic resins.

That the dielectric constant and especially the power factor at 60 cycles maintain their values almost unchanged over a wide temperature range is shown in Figure 7. Up to the heat distortion temperature range of about 145 C the power factor is excellent.

Table 3 points out liquids which are nonsolvents, poor solvents, good solvents and those reagents which attack the resin readily. Among the nonsolvents, petroleum ether, water, dilute aqueous acids, aqueous salt solutions and oil have no effect. Among the "poor solvents," those which dissolve the resin very slowly and incompletely, are benzene and toluene. Among the "good solvents" are pyridine and some pyridine-type bases.

The effect of lubricating oils and fluids is shown in Table 4. In general the bars are little affected at room temperature after one month in the oils as shown with the exception of the penetrating oil on the next to the last line. This material had an amine-type component which, as was pointed out before, attacks the resin. Table 5 shows the effect of raising the temperature to 125 C on parts submerged in four of the lubricating oils shown previously. Aside from a strong darkening of the parts, which parallels the darkening of the oils themselves, very little change occurred in parts in both one and three months' exposure. Table 6 shows the effect of a multipurpose grease and a stick lubricant.

In Table 7 resistance to gasoline is given. As the aromatic content of the gasoline increases the solvent power of the benzene and toluene-like compounds begin to take effect. The weight change is markedly different and the dimensions also are somewhat sensitive to these variations in composition. These results are not unexpected because benzene and toluene are classed as "poor solvents." Diesel fuel, on the other hand, which is mainly aliphatic, does not affect the bars to speak of.

The resin is non-corrosive to other materials and is combinative with other materials, especially metals. This is confirmed by results of a test worked out by Harold A. Perry of the Naval Ordnance Laboratory. In this test the material is ground to pass a 40-mesh screen and extracted with conductivity water. The extract is measured for conductivity as an indication of the tendency of the material under test to corrode other materials placed in contact with it.

Molded parts have been exposed outdoors in Pittsfield, Mass. for over a year with no apparent effect. These tests are continuing in Pittsfield and elsewhere.

Applications include housings for equipment to protect against environmental corrosion conditions, cases for sulfuric acid-lead storage batteries, encapsulated coils of wire, transparent oil bonnets which are satisfactory at the usual oil pressure of about 2000 psi, valve and pump parts, pipe lines, tanks or tank linings on the basis of acid resistance tests.

For example, after 120 hours in an evaporator with 8-15 percent free hydrofluoric at 82-121 C (180-250 F), the resin was evaluated as "good." In an acid settling tank where the parts were in 6 percent hydrofluoric at 60 C (140 F) for 120 hours, resistance of the parts was rated as "excellent." Further, an "excellent" rating was given after 120 hours in an effluent line waste tank at pH 11-12 at 43 C (110 F).

In another two-week test a valve containing a molded valve seat was subjected to 20 percent hydrochloric at 93 C (200 F) and 600 psi and also to intermittent opening and closing. The results indicated the seat was resistant to the medium and that it stood up under the pressure. It was rated as about the only material suitable for this application.

TABLE 2—Mechanical Properties

	Strength-psi	Modulus-psi
Tensile	8,000-9,000	160,000
Flexural	11,000-13,000	375,000
Compressive	11,000	240,000

TABLE 3—Chemical Stability

Non-Solvents	Good Solvents
Petroleum ether	Methylene chloride
Aliphatic hydrocarbons (hexane)	Chloroform
Alcohols (ethanol)	Chlorobenzene
Water	P-dioxane
Dilute aqueous acids	
Aqueous salt solutions	
Oil (ASTM 3)	
Poor Solvents	**Attacked By**
Acetone	Amines
Benzene	Ammonia
Toluene	Alkalies
Ethyl acetate	
Nitro benzene	

Dielectric Strength, S. T., ⅛" thickness--400 volts/mil

Dielectric Constant, 60 cycles -------- 3.17; 10^6 cycles -------- 2.96

Power Factor, 60 cycles ------ 0.0009; 10^6 cycles ------ 0.010

Volume Resistivity ---------- 2.1×10^{16} ohm-cm

Arc Resistance ---------- 10-11 seconds

Figure 6—Electrical properties.

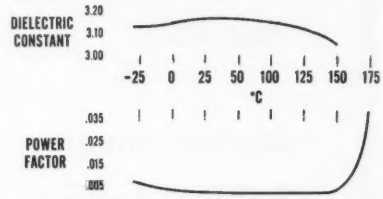

Figure 7—Effect of temperature on power factor and dielectric constant (60 cycles).

TABLE 6—Resistance of Polycarbonate Resin Bars to Grease and Stick Lubricant
Original dimensions—2.5" x 0.5" x 0.14"

Material*	After 3 Mo. at Room Temperature, Change In		
	Weight %	Thickness	Width
Multipurpose Grease	+0.04	nil	—0.002"
Stick Lubricant	+0.03	nil	—0.001

* No change in appearance.

TABLE 4—Resistance of Polycarbonate Resin Bars to Lubricating Oils and Fluids
Original dimensions 2.5" x 0.5" x 0.14"

OIL	After One Month at Room Temperature, Change In			
	Weight	Thickness	Width	Length
Regular	+0.045%	nil	+0.0015"	+0.001"
Detergent	+0.05	nil	+0.001	nil
Superdetergent	+0.05	nil	+0.002	+0.003
Transmission	+0.05	—0.001"	—0.001	+0.003
Light Lubricating	+0.05	nil	+0.001	nil
Penetrating	+0.4	nil	+0.002	+0.003
Brake Fluid	+0.1	nil	nil	nil

None of the samples were changed in appearance.

TABLE 5—Resistance of Polycarbonate Resin Bars to Lubricating Oils
Original dimensions 2.5" x 0.5" x 0.14"

OIL	Change After Aging at 125C (F) In						
	Weight		Thickness	Width	Length	Appearance	
	1 Mo.	3 Mo.	1 Mo.	1 Mo.	1 Mo.	1 Mo.	3 Mos.
Regular	—0.055%	—0.15%	nil	nil	—0.002"	Dark*	Dark*, opalescent
Detergent	—0.095	—0.105	nil	nil	—0.005"	Dark*	Very dark*
Superdetergent	—0.102	—0.10	nil	nil	nil	V. Dark*	Very dark*
Transmission	.....	+0.08	....	....	.....	.....	Very dark*

* Reflects darkening of oil on aging.

TABLE 7—Resistance of Polycarbonate Resin Bars to Gasoline
Original dimensions 2.5" x 0.5" x 0.14"

Type of Gas	After 1 Month at Room Temperature, Change In				
	Weight	Thickness	Width	Length	Appearance
Regular	+0.45%	nil	+0.002"	nil	No change
High Test	+1.1	nil	+0.003"	+0.003"	Reduced gloss
Super High	+1.5	+0.003"	nil	+0.002"	Badly etched
Diesel	+0.05	nil	nil	nil	No change

CORROSION ABSTRACTS

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2. TESTING

2.1 General

2.1.1

Some Concepts of Experimental Design. J. D. HROMI. *Corrosion,* **13,** No. 11, 739t-742t (1957) Nov.

Large masses of data in industrial experimentation are meaningless unless they can be reduced to a form from which it is possible to readily estimate the effect of existing conditions on the process or product. In the past, multiple-regression analysis and statistical quality control have been used in this connection with limited success. It is now possible to obtain more complete results through the use of a method developed by mathematical statisticians. This method is outlined and discussed in detail. It is shown how use of this technique enables an investigator to use each piece of data for making each conclusion and enables him to examine the behavior of one variable at more than one level of each of the other variables in the study. 14430

2.1.2, 2.2.8, 8.4.3

Interpretation of Tubing Caliper Surveys. VICTOR W. MAXWELL AND BEN D. PARK. *Corrosion,* **13,** No. 12, 828t-832t (1957) Dec.

An arithmetical interpretation of tabulated data is derived in an effort to obtain the maximum utilization of tubing caliper surveys. Analysis of consecutive surveys allows the engineer to determine the corrosion status of a string of oil well or gas well tubing and to assess a treatment efficiency. Limits assigned were based on field experience of grading tubing. Limits are therefore not inflexible and may be changed to meet specifications of any company or can be standardized throughout the industry as more information is compiled. The proposed method offers a simple yardstick to the corrosion engineer which previously was not available in the area of tubing caliper surveys. 14439

2.2 On Location Tests

2.2.2, 4.2.7

Corrosion of Metals in Tropical Environments. Part I. Test Methods Used and Results Obtained for Pure Metals and a Structural Steel. A. L. ALEXANDER, B. W. FORGESON, H. W. MUNDT, C. R. SOUTHWELL AND L. J. THOMPSON. Naval Research Laboratory, June, 1957, 46 pp. Available from: Office of Technical Services, U. S. Dept. of Commerce, Washington 25, D. C. (Order PB 121952).

The corrosion rates and characteristics of aluminum, lead, nickel, zinc, copper, and structural steel exposed for eight years to five tropical environments in the Panama Canal Zone are reported. Corrosion rate data are compared for each of the environments. This quantitative information is the first to appear in the literature, according to the report, and should have considerable value in the selection of metals for use in similar tropical locations.—OTS. 14576

2.2.2, 5.4.5

Outdoor Exposure of Acrylic Emulsion Paints. I. Results of Outdoor Exposure on Panels. GEROULD ALLYN. *Paint and Varnish Production,* **47,** 39 + 4 pages (1957) May.

Paint formulations and exposure characteristics.—BTR. 14580

2.2.5, 5.4.5, 7.5.5

Epoxy Coatings Perform Well on Steel Exposed to Chemicals, Corrosive Atmospheres. WILLIAM M. BRACKETT. *Corrosion,* **13,** No. 11, 144, 146 (1957) Nov.

Case histories are given of successful use of epoxy coating systems on steel surfaces exposed to chemicals and corrosive atmospheres. Equipment coated includes floating roof type tanks, solvent tanks, paper mill tanks and structural steel. Good performance in competition with other generic types for periods up to 5 years is reported. A paper presented under the title "An Examination of Epoxy Type Industrial Maintenance Coatings" at a meeting of Northeast Region, National Association of Corrosion Engineers, Philadelphia, Pennsylvania, October 15-17, 1956. 14416

2.3 Laboratory Methods and Tests

2.3.9

Nuclear Irradiation and Radioisotopes in Metal Research. MASSOUD T. SIMNAD. General Dynamics Corp. *Intern. J. Appl. Radiation and Isotopes,* **1,** 145-171 (1956) Nov.

This review covers a wide range of topics in the field of metal research where nuclear irradiation and radioisotopes have been employed. Nuclear irradiation has been used both as a means to detect minute quantities of impurities or minor constituents and as a powerful tool for carrying out studies of the structure of metals. Radioisotopes have found increasing application in almost all branches of metal research, namely,

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in studies of segregation, friction, vapor deposition, vapor pressure, slag metal reactions, electrolytic action on metal surfaces and diffusion and oxidation. (auth.)—NSA. 13679

2.3.9

Measuring Trace Elements by Activation Analysis. ROBERT C. PLUMB. *Nucleonics*, **14**, No. 5, 48-49 (1956).

Trace elements at concentrations of a few ppm can be analyzed in aluminum. Sodium can be determined with a precision of ±1% and limiting accuracy of 0.0001%; phosphorus >0.0001% can be analyzed within 5%. The limiting sensitivity for phosphorus is 5×10^{-7}%. If an aluminum alloy is irradiated, a variety of radioisotopes are produced, some of which may mask the presence of others. Copper, gallium and the rare earths can be detected at levels <1 ppm. Zone-refined super-purity aluminum, containing magnesium 1, iron 2, copper 0.5 ppm and undetected amounts of 17 other elements was studied. Activation analysis revealed the positive presence of zirconium at the 5-ppm level. Molybdenum, iron, copper and gallium were identified with reasonable certainty. Information on the mechanism by which mercury increases the corrosion rate of aluminum was obtained by an autoradiographic technique.—MA. 13677

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2.3.9

Study of Surface Films by Means of X-Ray Fluorescence. C. LEGRAND AND J. J. TRILLAT. *Rev. Met.*, **53**, No. 8, 645-648 (1956).

The thickness of thin films is measured by the emission of characteristic rays from material subjected to selective X-radiation when the films are held on a support whose fluoresence is not excited. The intensity of the fluorescence due to a thin film increases linearly with the thickness within a certain range of thicknesses. The sensitiveness varies greatly according to the angle of incidences. A Geiger-Muller counter provides a rapid means of measurement. Examples are given of the application of the method.—MA. 13633

2.3.9, 1.4, 2.4.3

The Literature of Radioactive Testing Techniques: Selected References 1950-1956. J. M. DALEY AND J. B. NORTH. U. S. Special Libraries Assoc., Metals Div., Publications on Industrial Uses of Atomic Energy, October 11, 1956, 7 pp. Special Libraries Association, 31 East 10th Street, New York 3, N. Y.

Lists about 100 references, no abstracts, on general radioactive testing techniques, metal structure and analysis, metal processing, inspection of castings, inspection of welds, gauging, wear studies, wear of engines, of machinery, tool life, corrosion and oxidation, metal cleaning and electrical contact.—BNF. 13524

2.3.9, 5.3.2

The Nature, Cause and Effect of Porosity in Electrodeposits. II. Radiographic Detection of Porosity in Electrodeposits. F. OGBURN AND M. HILKERT. *Tech. Proc. Am. Electroplaters' Soc.*, **1956**, 256-259, 288-299.

A new method in which deposits are plated 0.001 to 0.003-inch thick on basis metals and radiographed by X-rays or radioactive sources. The smallest discontinuities detected in this study were 0.001 to 0.002-inch diameter but it is suggested that microradiographic techniques would greatly increase the possible resolution. Radiographically detected discontinuities almost always formed corrosion sites in atmospheric exposure tests but most corrosion sites were found where no discontinuities were detected by radiography.—BNF. 13680

2.3.9, 1.6

Methods for Emission Spectrochemical Analysis. Book, 1957, 488 pp. Available from American Society for Testing Materials, 1916 Race Street, Philadelphia 3, Pa.

This book, sponsored by ASTM Committee E-2 on Emission Spectroscopy collects under one cover much of the reliable information on this method of analysis, which grows rapidly in popularity as the need to identify very small quantities of materials becomes more pressing. Workers in corrosion, especially those concerned with analysis of corrosion products, often find spectrochemical analysis useful.

Committee E-2, which has been engaged in a program leading to standardization of spectrochemical practices since 1932, points out that in the present state of knowledge about this specialty much of the data and procedures are not specifically adopted. The book is divided into four major sections, general practices, nomenclature, spectrochemical analysis of metals and spectrochemical analysis of non-metals. As usual in ASTM publications, the data are complete, concise and authoritative. 14855

2.4 Instrumentation

2.4.2

A Simplified Method for Making and Maintaining Half-Cells. LEWIS P. AKER. *Corrosion*, **13**, No. 9, 122 (1957) Sept.

A method is described for making inexpensive copper-copper sulfate half cells that compare favorably in characteristics with recommended behavior of half cells in technical literature. Routine handling of these cells is described. This paper was presented under the title "The Care and Feeding of Half-Cells" at a meeting of Northeast Region, National Association of Corrosion Engineers, Niagara Falls, N. Y., October 31-November 3, 1955. 14380

2.4.2

Variability in Working Copper Sulfate Half Cells: Topic of the Month. K. G. COMPTON. *Corrosion*, **13**, No. 3, 149t-150t (1957) March.

Three sets of measurements made to study reproducibility of measurements with working half cells. A group of 13 copper sulfate half cells was used. Results indicate that differences in potential measurements between structures and half cells or between half cells below 10 mv have little significance. 14397

2.4.2

Testing Machine for Short-Time Creep and Stress-Rupture Testing at 2000 to 2500 C. M. C. SMITH, D. M. OLSON AND H. L. BROWN. University of California. *Rev. Sci. Instruments*, **28**, No. 7, 543-547 (1957) July.

Description of a testing machine in which a specimen contained within a water-jacketed vessel is heated in vacuum or in a gas atmosphere by a tantalum-tube resistance heater and is then subjected to static tensile loads up to 100,000 psi. This machine is now in routine use at Los Alamos Scientific Laboratory for short-time creep and stress-rupture testing of metallic and non-metallic specimens at 2000-2500 C. With minor modifications, it can also be used for longer-period creep and stress-rupture studies, for ordinary tensile, compressive or shear testing and for operation at temperatures substantially above 2500 C or down to room temperature. Photos, diagrams.—INCO. 14781

2.4.2, 4.6.5, 8.4.5

Measurement of Corrosion Products in High Temperature, High Pressure Water System. A. A. SUGALSKI AND S. L. WILLIAMS. *Corrosion*, **13**, No. 9, 572t-574t (1957) Sept.

The concentration of corrosion prod

ucts and other impurities which produce undesirable radionuclides must be maintained at extremely low values in the primary coolant systems of nuclear power plants to keep the resulting radioactive dose rate below certain maximum values. In the development of purification systems for maintenance of these low concentrations it is necessary to measure the concentration of the various impurities and their solubility as they exist at the primary coolant temperature. This paper describes the development of a high efficiency filter used for this purpose and gives data obtained from both radioactive and non-radioactive water systems. 14775

2.4.3, 5.3.2

Measuring Thickness of Sprayed Metal Coatings. R. E. MANSFORD. *Electroplating and Metal Finishing*, **10**, No. 7, 208-212, 220 (1957) July.

Differences between plated and sprayed metal coatings are given. Types of testers (pull-off gages, moving iron types and electro-magnetic instruments and their choice are discussed. Details of setting up instruments and errors in calibration or in setting up of instruments and other sources of error are given. Other thickness testers are mentioned.—BL. 14712

2.4.3, 3.7.3

Methods of Ultrasonic Testing of Welds. S. T. NAZAROV AND YU. P. PANOV. *Zavodskaya Laboratoriya*, **23**, No. 3, 305-308 (1957).

Methods of scanning welds for lack of fusion at edges and for internal defects, using inclined-face search units that introduce sound waves into the base metal well away from the actual weld side, with direct or reflected incidence of the sound on the weld. Nomogram for solution of the equations involved in determining depths and choosing the correct distance between transducer and weld, etc., constructed for a transducer with a face inclined at 40 degrees to the surface through which the sound waves travel. Standard for setting sensitivity for butt welds and practical example are given.—HB. 14329

3. CHARACTERISTIC CORROSION PHENOMENA

3.2 Forms

3.2.2, 3.6.5

Events at a Scratch-Line. U. R. EVANS. 4th Hothersall Memorial Lecture before Inst. Metal Finishing, Brighton, April 12, 1957. *Trans. Inst. Metal Finishing*, **34**, 139-166 (1957); *Bull. Inst. Metal Finishing*, **7**, No. 2, 139-166 (1957) Summer.

Surface defects on bare metal which constitute starting points for corrosion are discussed. Where protective coatings are applied, defects sometimes contribute to imperfections in coating. Scratch-line engraved under definite load represents reproducible type of defect and has been used at Cambridge University in corrosion mechanism research. Scratching machine (Mears-Ward) is described. Visible and invisible oxide films, and possibility of oxide-removal by abrasion are considered. Statistical experiments show that probability of corrosion at scratch line wetted with liquid standing on border-line between corrosive and passivating classes decreases steadily with period of air-exposure before wetting; also, corrosion at one scratch-line depresses probability of corrosion starting at adjacent scratch-line (mutual) protective effect). Corrosion is quantitatively related to electric currents flowing between scratch as anode and surrounding region as cathode. Importance of stress left after scratching and stress distribution around scratch-line are discussed. Stress situations on metals oxidized by inward movement of oxygen and on metals oxidized by outward movement of oxygen, and possibilities of simultaneous movement of both ions are considered. Phenomenon of crack-heal is demonstrated experimentally. Scratch-line experiments on nickel are discussed. Effect of surface condition on corrosion below protective coat, and significance of scratch-line results to electrodepositor are presented. Graphs, 34 references.—INCO. 14722

3.2.2, 6.2.4, 7.10

Brittle Fracture of Sheet Piling. W. A. MORGAN AND R. C. A. THURSTON. *Metal Progress*, **71**, No. 3, 86-91 (1957) March.

Failures in sheet piling are due to driving failures where fracture is propagated from flame-cut handling hole, failures during service, where fracture is propogated from flame-cut tie-rod holes, drain holes or bolt-holes and brittle fractures initiated by fatigue cracks. Results of metallurgical examination and tensile tests on alloy steels containing 0.064, 0.03 and 0.02 nickel, plain carbon

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steels containing a trace of nickel and high phosphorus steels containg 0.04-0.05 nickel are given. Service behavior of steels indicates that low-temperature brittle fracture occurred in almost all samples possessing a 15 ft. lb. transition temperature higher than service temperature. A marked feature of all samples is that transition temperature increased with increasing tensile strength. Phosphorus was very effective in increasing notch brittleness. Failures are traced to irregularly flame-cut holes, poor welding techniques and corrosion pits. Results show that sheet piling specifications should call for lower carbon and higher manganese contents. Graphs, tables, photos.—INCO. 13799

3.2.3, 6.2.2

Plastic Flow of Iron Oxides and the Oxidation of Iron. J. D. MacKenzie and C. E. Birchenall, *Corrosion*, **13**, No. 12, 783t-785t (1957) Dec.

Under certain conditions, the oxidation of iron in oxygen at high temperatures is accompanied by the formation of a central box-like cavity the dimensions of which are identical to those of the original iron specimen. The decrease in size of this cavity with increasing temperature and its disappearance when the formation of magnetite and hematite is excluded by a controlled oxidizing potential indicates that the plastic properties of the oxides may be an important factor. This is qualitatively confirmed by the measurement of the relative plasticity of the three oxides at 800-1000 C in a specially designed apparatus. 14455

3.2.3, 6.3.17

The Oxidation of Uranium in Argon Containing Traces of Oxygen. D. Shaw and P. Hindmarch. April, 1957, 11 pp. Windscale Works, Sellafield, Cumb., England.

The rates of oxidation of uranium in argon containing up to 50 ppm. oxygen at temperatures up to 900 C have been investigated. The oxygen content of the argon was measured using an electrolytic cell method. The rates of oxidation in argon containing up to 10 ppm. oxygen were considerably less, proportionally, than the rates obtaining at 30 and 50 ppm. oxygen. The rates of oxidation at 600 and 900 C were similar, but at 300 C the rate was appreciably less. The results indicated that the initial rate of oxidation is slow but increases to become linear with time after the oxide thickness exceeds a certain value. (auth) —NSA. 14763

3.4 Chemical Effects

3.4.8, 4.6.2

Effect of Zinc Ion on Corrosion of 2S Aluminum, Type 347 and SAE-1020 Steel in Static Water at 500 F. C. Wohlberg. Argonne National Laboratory. U. S. Atomic Energy Commission Pubn., ANL-5399, May, 1956, 36 pp.

A series of tests were made to evaluate the influence of zinc ion on the corrosion behavior of Type 347 stainless steel, 2S aluminum and SAE-1020 steel in static water at 500 F.—BTR. 12650

3.4.8, 3.8.3, 6.2.5

Effect of Halogen Ions on the Anodic Passivation of Stainless Steels. (In Japanese.) Susumu Morioka and Kazutaka Sakiyama. *J. Electrochem. Soc.*, Japan, **25**, No. 4, 191-195 (1957) April.

It has been generally understood that the chlorine ion, due to its small radius and a large penetrating power, activates the passive film by penetration and destruction. However, the ionic radii of halogen ions are given in Table 1, and it is doubtful that the small ionic radius is the cause of the activation.

Experiments have been carried out on the anodic polarization of various stainless steels and their constituent metals in 5 percent sulfuric acid, neutral solution, and N sodium hydroxide solution containing an equivalent concentration of halogen ions, respectively. The results are given. The following interesting fact was observed: in acidic or neutral solution the dissolution of the passive stainless steels takes place below the proper dissolution potential of Cr^{VI} in the presence of Cl^-, and Br^-, whereas in alkaline solution the stainless steels are attacked by Br^- and I^-, not by Cl^-.

The above fact is favorably explained by the relationship by the discharge potential between the oxygen and halogen ions and by the oxidizing power of the discharged oxygen and halogen elements. That is, the dissolution of passive stainless steels does not depend upon the penetrating power of halogen ions, but the oxidizing power of discharge halogen elements when it is larger than that of the oxygen in the solution. For example, the fluorine does not affect the dissolution of passive stainless steels because it is hardly discharged in aqueous solutions. The fact that the action of Cl^- is weaker than Br^- or I^- in alkaline solution is because the former is not readily discharged and the oxidizing power of the iodine is larger than that of the oxygen in alkaline solution. That the action of the chlorine is the most effective in general is due to the largest oxidizing power among halogen elements which are more dischargeable than the oxygen.—JSPS. 14396

3.4.9, 6.4.2

Action of Heated Water on the Surface of Aluminium. Ichiro Sato. *Denki Kagaku (J. Electrochem. Soc., Japan)*, **25**, 8-12 (1957); *Chem. Absts.*, **51**, No. 9, 6466 (1957) May 10.

Through electron microscope observations and electrode potential measurements, an examination was made of how the anticorrosive surface is formed on an aluminum foil immersed in hot water (>80 percent). In the hot-water treatment the foil first forms eroded surfaces with lower electrode potential. When the foil is washed and dried, aluminum hydroxide is deposited on the "anodes" of the local cells formed on the surface of the foil.—ALL. 14428

3.4.9, 3.8.4, 6.3.17, 4.6.2, 8.4.5

The Uranium-Steam Reaction. R. A. U. Huddle. Gt. Brit. Atomic Energy Res. Establishment, Harwell, Berks, England, M/R-1281, Nov., 1953 (Declassified April 16, 1957), 18 pp.

Experiments on the rate of reaction between uranium and steam at temperatures up to 600 C are described. The rate increases rapidly above 200 C reaching a maximum in the range 250 to 400 C; above this temperature it drops considerably, remaining practically constant between 450 and 600 C. The heats and free energies of the fundamental reactions of the system, uranium-steam, have been calculated for temperatures up to 5000 K. A new theory why oxide scales of some metals are protective whereas others flake or powder is presented. It is suggested that the Pilling-Bedworth ratio (the ratio of the volume of oxide produced to the volume of metal destroyed) is inappropriate and that protection is a function of the sintering characteristics of the oxide at its formation temperature. The results are discussed in relation to the kinetics of the uranium-steam and uranium-oxygen reactions which in turn are related to the problems associated with sudden failure of a water-cooled reactor. It is unlikely that any serious explosion will result from the chemical energy associated with this reaction. (auth).—NSA. 14661

3.4.10, 5.8.4, 6.4.4

Influence of Wetting Agents on the Corrosion of $AlMg_7$ with Particular Consideration of Corrosion Fatigue. E. Gebhardt and H. Beyer. *Z. Metallkunde*, **48**, No. 5, 232-240 (1957) May.

Deals with influence of various wetting agents on corrosion behavior of $AlMg_7$ in following corrosive media: distilled water, sea water, 3 percent sodium chloride solution, hydrochloric acid and caustic soda. Results are based on long-time immersion tests, stress corrosion tests, and corrosion fatigue tests. Corrosion behavior was determined by appearance of specimen, resulting weight loss (immersion tests), life of bend specimen (stress corrosion test) and shape of the Wöhler curves (corrosion fatigue test). To carry out fatigue corrosion test, an endurance testing machine was developed which permited simultaneous testing of 100 specimens under various strengths of alternating bend stresses. Investigations showed that wetting agents can inhibit or promote action of corrosive media studied. Anion-active wetting agents produce distinct increase in corrosion resistance to sea water, sodium chloride solution, hydrochloric acid and caustic soda; in distilled water, however, they lead to increased attack. The influence of cation-active wetting agents in sea water, sodium chloride solution and hydrochloric acid was only slight in most cases. Non-ionic additions produced acceleration of corrosion processes in caustic soda and distilled water, while only slight changes were noted in rest of corrosive media. In bend specimens, location of fracture was dependent on wetting agent. With addition of anion-active agents, it was located in less deformed part of specimen at surface of liquid; in all other cases it was in region of severest bend. Shape of Wöhler curves was also dependent on type of wetting agent used. Anion-active agent resulted in increased fatigue resistance, whereas non-ionic agent produced no noticeable change in fatigue resistance. Tables, graphs.—INCO. 14432

3.5 Physical and Mechanical Effects

3.5.9, 6.3.20

Surface Flow Phenomena in the Course of High-Temperature Oxidation. The Case of Zirconium and Its Alloys. (In French.) D. Whitwham, J. Boghen and J. Herenguel. *Rev. Aluminium*, **34**, 611-623 (1957) June.

The oxidation of zirconium was studied in air in the temperature range 400-1050 C for time intervals ranging up to 24 hours. It was found that below 500 C a thin, compact oxide film adheres to and protects the metal. Above 500 C the metal below the surface undergoes a real transformation due to the expansion

which takes place during the conversion of the metal into its oxide. 9 references. —MR. 14814

3.5.9, 6.2.1

Formation of Scale on Iron and Iron Alloys at High Temperatures. (In Russian.) V. I. TIKHOMIROV. Leningradskogo Universiteta, *Vestnik Seriia Fiziki i Khimii*, **12**, No. 4, 85-101 (1957).

The process of wustite oxidation in air at high temperatures is shown to follow the parabolic law. The coefficient of diffusion of iron through a wustite layer is calculated. Extensive data and usable equations are reported. Effect of moisture, oxygen and hydrogen. 4 tables, 4 figures, 27 references. (Translation available: Associated Technical Services, P. O. Box 271, East Orange, New Jersey.) 14832

3.5.9

Quality Control of High-Temperature Alloys. G. T. HARRIS. *Metal Progress*, 71, No. 1, 90-94 (1957) Jan.

If variations in properties of high-temperature alloys were reduced, alloys could be used at higher temperatures or higher stress levels than are now safe. Investigations of scatter included studies on Nimonic 90 and 95, cobalt-rich alloys G32 and G34 and alloy G42 B. Study of additions of cobalt, iron, nickel and chromium to a cobalt base alloy showed that a 45 cobalt, 12 nickel and 20 chromium base would give the best balance of high rupture strength, low cost and machinability. Investigation of warm working of steel, G 42 B turbine blade alloy and G 34 castings showed that vacuum melting reduced variations in properties. Scatter can be metallurgically controlled and reduced and average level of properties raised by 14 percent. Causes of scatter are listed.—INCO. 14663

3.5.9, 3.8.4

New Aspects of Metal and Alloy Oxidation at High Temperatures. (In French.) J. BENARD. *Corrosion et Anticorrosion*, **5**, 138-145 (1957) May.

Nucleating process when the oxide film begins to form. Changes in the surface microstructure of the metal after being exposed for a long time to a very slightly oxidizing atmosphere. Practical consequences.—BTR. 14584

3.5.9

High Temperature Oxidation of Metals and Alloys. (In Norwegian.) Per. Kofstad. *Teknisk Ukeblad*, **104**, 225-230, 249-254 (1957) March 21, March 28.

Recent theories concerning the oxidation of metals and alloys at temperatures above 500 C. Principal requirements for the development of new oxidation-resistant alloys.—BTR. 14326

3.5.9, 4.3.3, 5.8.2, 4.2.3

A Thermochemical Study of Some Additives to Reduce Residual Fuel Ash Corrosion. W. E. YOUNG AND A. E. HERSHEY. *Corrosion*, **13**, No. 11, 725t-732t (1957) Nov.

Based on the premise that liquid fuel-ash components are associated with the "catastrophic" attack on refractory alloys, a theoretical study has been made of mixtures of vanadium pentoxide and sodium sulfate with various metallic oxides and sulfates. The thermal stabilities of the sulfates were then investigated. It was concluded that the oxides of calcium, magnesium, and aluminum should be effective if they could be preserved in the oxide form. However, it was shown that the sulfate would in general be the stable form, particularly at gas turbine operating pressures. Such sulfates are not effective additives and may, in fact, be deposit forming. The additive with the most promise was found to be an aluminum compound. Its sulfate, even if initially formed, should revert almost entirely to the oxide at 800 C for atmospheric conditions and 920 C at five atmospheres. Some of these conclusions have been confirmed by full scale tests on turbines, but additional laboratory testing and actual operation are necessary to verify them completely. More extensive and accurate thermochemical data would contribute to the validity of the calculated results. 14407

3.6 Electrochemical Effects

3.6.2, 5.8.3

Mechanism of the Corrosion of Metals in Narrow Crevices and Gaps. Pt. II. Corrosion of Iron in Solutions of Corrosion Inhibitors. (In Russian.) I. L. ROZENFEL'D AND I. K. MARSHAKOV. *J. Phys. Chem., USSR (Zhur. Fiz. Khim.)*, **31**, No. 1, 72-82 (1957) Jan.

The corrosion of iron at points situated within narrow crevices or gaps was studied by immersing two specimens in parallel relation, with a 50 mm. gap therebetween, into river water containing a conventional corrosion-retarding agent. Under these conditions, zinc sulfate inhibits corrosion. Sodium nitrite, disodium phosphate, and potassium bichromate cause intensified corrosion because of difficult access into the close clearance. Maximum corrosion was observed not at the crevices of minimal width, but at intermediate values, determined by the temperature, inhibitor concentration, and other factors. 14437

3.6.5, 2.1.1, 5.2.4

Protective Potentials of Metals. V. V. GERASIMOV. Bull. Acad. Sci. U.S.S.R. *(Izvest. Akad. Nauk S.S.S.R.), Chemical Sciences Division*, No. 3, 263-269 (1957) March.

A new method is given for calculating protective potentials. The calculated values agree well with the experimental ones for copper, zinc, cadmium, magnesium, lead, iron and cast iron in 1.5 percent sodium chloride solution, and for iron in synthetic lake-water. 3 figures, 3 tables, 9 references.—ATS. (Translation available: Associated Technical Services, P. O. Box 271, East Orange, New Jersey.) 14406

3.6.2, 3.8.2

The Oxygen Concentration Cell as a Factor in the Localized Corrosion of Metals. WILSON LYNES. *J. Electrochem. Soc.*, **103**, No. 8, 467-474 (1956) Aug.

Literature on the oxygen concentration cell has been reviewed. The discovery and

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early history of the cell are outlined and environmental conditions favorable to its development are classified and discussed. Theories of the mechanism of the cell are presented. The current produced by an oxygen concentration cell is considered in terms of the open-circuit potentials and polarizing characteristics of the anode and cathode and the resistance of the metal and electrolyte. Selected quantitative data are shown in tabular and graphic form. 98 references. 12503

3.6.6, 7.2, 2.3.1

Galvanic Corrosion in Water Meters. HERBERT F. BARRETT. *J. Am. Water Works Assoc.*, **48,** Pt. 1, 1235-1242 (1956) Oct.

Laboratory test limitations: definition of galvanic corrosion; common glavanic couples.—BTR. 13510

3.6.6

Electrochemical Corrosion in Relation to Engineering Design. (In English.) S. L. CHAWLA. *Electrochem. Soc., Bull. India Section,* **5,** 77-82 (1956) Oct.

Factors leading to galvanic corrosion and their practical implications. Protective measures. 10 references.—BTR. 13952

3.6.6, 3.5.9

Thermogalvanic Corrosion. V. V. GERASIMOV AND I. L. ROZENFEL'D. Bull. Acad. Sci., USSR (Izvestiya Akad. Nauk), *Chem. Sci. Div.*, No. 1, 29-31 (1957) Jan.

Currents of thermogalvanic pairs of copper, iron, nickel and lead were measured in neutral, basic and acidic solutions at various temperatures and ratios of cathode to anode surface. Effect of these factors on thermogalvanic corrosion was studied. 1 figure, 2 tables, 4 references.—ATS. Translation available: Associated Technical Services, P. O. Box 271, East Orange, New Jersey. 13898

3.6.6, 5.2.2

Galvanic Corrosion. Pt. I. Current Flow and Polarization Characteristics of the Aluminum-Steel and Zinc-Steel Couples in Sodium Chloride Solution. M. J. PRYOR AND D. S. KEIR. *J. Electrochem. Soc.*, **104,** No 5, 269-275 (1957) May.

Current flow, weight loss and polarization measurements have been carried out on the aluminum-mild steel and zinc-mild steel couples in normal sodium chloride solution at 25 C. Under a wide variety of experimental conditions both aluminum and zinc are anodic to mild steel and completely protect it against corrosion. In both galvanic couples the current flow and weight losses of the anodes are proportional to the area of the steel cathode and are much less dependent on the anode area. Galvanic corrosion rates of both couples appear to be controlled by oxygen depolarization and are thus markedly increased by stirring. At high stirring rates, the aluminum-steel couple delivers a much higher galvanic current than the zinc-steel couple. 13855

3.6.8

Investigation of Phase-Boundary Impedance for Noble-Metal Electrodes in the Region of Hydrogen Adsorption. II. Activated Iridium and Activated, Aged Rhodium Electrodes. M. BREITER, H. KAMMERMAIER AND C. A. KNORR. *Z. Elektrochem.*, **60,** No. 2, 119-127 (1956).

With apparatus and methods as described in Part I the frequency and potential dependency of the phase-boundary impedance is found for activated iridium and activated, aged rhodium bathed in hydrogen with 8N-sulfuric acid as electrolyte. A reproducible surface-condition of maximum activity was obtained by a short anodic treatment. Compared with platinum, iridium and rhodium show a narrower potential range for hydrogen adsorption and a frequency dependency of phase-boundary impedance which for positive over-voltages indicates a reduction of the hydrogen adsorption process. The overvoltage for DC is determined by hydrogen diffusion up to the limiting value where gas bubbles form. 11 references.—MA. 13911

3.6.8

Concentration Polarization and Overvoltage. CECIL V. KING. *J. Electrochem. Soc.*, **102,** No. 4, 193-197 (1955).

A discussion of the magnitude of concentration polarization to be expected in the measurement of hydrogen overvoltage. The use of the Nernst-Fick equation to calculate its effect is illustrated for acid, alkaline and buffered solutions. 16 references.—MA. 10804

3.6.8, 3.5.6, 6.3.11

Mechanisms of Hydrogen-Producing Reactions on Palladium. II. Diffusion of Electrolytic Hydrogen Through Palladium. SIGMUND SCHULDINER AND JAMES P. HOARE. *J. Electrochem. Soc.*, **103,** No. 3, 178-181 (1956).

Cf. *ibid.*, **102,** 485 (1955). The rate of diffusion of hydrogen through several thicknesses of palladium for varying current densities was measured. The relationship between the diffusion current and the total polarizing current was established. 10 references.—MA. 12982

3.6.8, 6.3.20

Anodic Overpotential for Oxide-Free Zirconium. MARIO MARAGHINI, GEORGE B. ADAMS, JR. AND PIERRE VAN RYSSELBERGHE. Oregon University. U. S. Atomic Energy Comm. Pubn., AECU-3467, May 1, 1957, 13 pp. Available from Office of Technical Services, Washington, D. C.

The estimation of the potential that a polarized zirconium anode would exhibit if it were free of oxide film is presented. (auth).—NSA. 14736

3.6.8

Electrochemical Polarization. Pt. III. Further Aspects of the Shape of Polarization Curves. MILTON STERN. *J. Electrochem. Soc.*, **104,** No. 11, 645-650 (1957) Nov.

The shape of electrochemical polarization curves is discussed for ideal systems containing more than two oxidation-reduction reactions. Situations are described where measured Tafel parameters have no direct relationship to the parameters of any of the oxidation-reduction reactions. The analysis, while containing several simplifying assumptions, shows the complexity of polarization measurements and indicates the care which must be taken if such measurements are to be interpreted quantitatively. 14778

3.6.8, 6.3.15

The Electrochemical Behavior of Titanium in Aqueous Solutions of Electrolytes. Pt. I. Hydrogen Overpotential of Titanium. (In Russian.) YA. M. KOLOTYRKIN AND P. S. PETROV. Karpov Moscow Physico-Chemical Inst. *J. Phys. Chem., USSR (Zhur. Fiz. Khim.),* **31,** 659-671 (1957) March.

The hydrogen overpotential in titanium was measured over a wide range of current densities from 10^{-2} to 10^{-1} a/cm² and pH values from 1 to 14.—NSA. 14672

3.6.8

Investigation of Phase-Boundary Impedance for Noble-Metal Electrodes in the Region of Hydrogen Adsorption. III. Freshly Activated Rhodium and Gold Electrodes. M. BREITER, H. KAMMERMAIER AND C. A. KNORR. *Z. Elektrochem.*, **60,** No. 5, 454-462 (1956).

The frequency and potential dependence were studied for freshly activated rhodium and gold electrodes bathed in hydrogen with 8N sulfuric acid as electrolyte. For positive overvoltage >0, low hydrogen adsorption is found on fresh rhodium. For overvoltages $< +50$ mV the effect of diffusion of molecular hydrogen is noticeable. On flat gold electrodes a hindrance to the formation of H^+ ions and the formation of hydrogen molecules is found and because of this the influence of hydrogen diffusion is no longer perceptible. 23 references.—MA. 13941

3.6.8

Corrosion Rate of Iron in Acid Solution and Its Polarization Characteristics. Y. TORIGOE. *J. Electrochem. Soc. Japan,* **24,** No. 9, 409-414 (1956) Sept.

All experiments and interpretations are performed on the corrosion of pure iron immersed in an unagitated solution of 1/10 N sulfuric acid.

Main experiments and their results obtained are as follows:

1. Polarization curves of all elements about local anode and cathode in the steady states are given. The author supposes that each curvature of anode and cathode curves is attributed respectively to the variations of the local anode area by external polarization and the repolarizing action of oxygen in solution by cathodic reaction.

2. Potential-time curves with application and interruption of external polarizing currents: In this case potential displacement with lapse of time can be roughly distinguished into two parts—a rapid potential rise during 0-50 msec after application (or interruption) of external polarizing current and a slow potential decrease extending over several minutes. According to the author's interpretation, the former is influenced mainly by the transient phenomena of the polarizing potential of each local element and the latter is related to the gradual variation of their surface areas.

3. Relation between electrode potential and corrosion current of various test pieces under natural corrosion conditions: It is interesting that a group of many points on the figure showing each natural corrosion state of various test pieces coincides with the polarization curve of local cathode.

Conclusions: 1. In the natural corrosion states of iron immersed in still aerated acid solution, the cathode area of the local cell seems to occupy the greater part of its total effective surface area. 2. When iron is polarized anodically by external current, there is a tendency that the local anode area increases to a definite value and the local cathode area decreases also to a definite value. However, in cathodic polarization, the variation in area of each local element is unlikely. 3. The corrosion rate of iron having less noble electrode potential is faster than that of iron having noble potential and the relation between electrode potential and corrosion current in natural corrosion state is as aforesaid.—JSPS. 13928

3.6.8

Electrolytic Hydrogen Evolution Kinetics and Its Relation to the Electronic and Adsorptive Properties of the Metal. B. E. CONWAY AND J. O'M. BOCKRIS. Univ. of Pennsylvania. *J. Chem. Phys.*, 26, 532-541 (1957) March.

A significant correlation between the logarithm of the exchange current density i_0 of the electrolytic hydrogen evolution reaction and the electronic work function ϕ is found for one group of metals. Another group of metals probably having a different relationship is distinguished. The relationship between $\log i_0$ and ϕ is explained as arising from the dependence of heat of adsorption upon ϕ. A general theory of electrolytic reduction and electrode poisoning is given. A mathematical analysis of the dependence of the rate of the proton discharge reaction in terms of the heat of adsorption of hydrogen, MH bond force constants and internuclear distance, is given. (auth) —NSA. 14153

3.6.8, 2.3.5

Investigation of Phase-Boundary Impedance for Noble-Metal Electrodes in the Region of Hydrogen Adsorption. I. Activated Platinum Electrodes. M. BREITER, H. KAMMERMAIER AND C. A. KNORR. *Z. Elektrochem.*, **60**, No. 1, 37-47 (1956).

A circuit is described for measuring the AC resistance of a polarized, activated platinum electrode bathed in hydrogen with a 8 N-sulfuric acid electrolyte. The frequency and potential dependency of the AC resistance is found for a range of over-voltages and this is connected with the adsorption of hydrogen atoms, the diffusion of hydrogen molecules and the discharge of H^+ ions. 34 references.—MA. 13915

3.6.9

Research on Corrosion Produced by Alternating Currents. (In French.) LUCIEN AMY AND CLAUDE MOUNIOS. *Rev. Gen. Elec.*, **66**, 187-188 (1957) March.

Laboratory experiments establish possibility of production of notable corrosion phenomena on metal piping by means of stray alternating currents of industrial frequency.—MR. 14544

3.7 Metallurgical Effects

3.7.4, 3.8.2, 6.4.4

Investigations of Corrosion Resistance in Sold Metallic Solutions. II. Magnesium-Cadmium Alloys. (In Russian.) N. N. GRATSIANSKII AND P. F. KALYUZHNAYA. Kiev Inst. of General and Inorganic Chemistry. *J. Phys. Chem., USSR* (Zhur. Fiz. Khim.), **30**, 1267-1277 (1956) June.

The resistance of two structural types of magnesium-cadmium solid solutions to corrosion in 1.0N sulfuric acid and 5% ammonium chloride at 16 and 40° has been investigated. Measurements were made of the potentials of the corroding alloys. The corrosion stability limits of the alloys, determined by weighing appear on the composition-corrosion-stability diagrams in concentrations below 75 at.% magnesium. The curves show the potentials of corroding alloys changing with the composition without any sharp breaks. The loose textured layer on the alloy surface measured by microhardness method increased after corrosion from 1 to 2μ to 3 to 4μ. (trauth)—NSA. 13571

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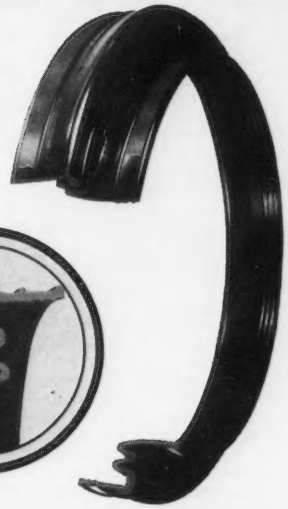

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3.7.4, 3.7.3, 6.2.3

Further Studies on the Effect of Microstructure on Notch Toughness and Fracture Morphology. J. C. Danko, J. H. Gross and R. D. Stout. Paper before Am. Welding Soc., Nat'l. Fall Mtg., Cleveland, October 8-12, 1956. *Welding J.*, **35**, No. 12, 604s-609s (1956) December.

Investigation to determine influence of some types of discontinuous phases in nominally constant ferrite matrix on notch toughness of aggregate. C1030 was the low-carbon steel studied. Table summarizes heat treatments used to produce various microstructures, transition temperatures, grain size of ferrite, aggregate size of discontinuous phase, microhardness values and tensile properties of microstructural aggregates, Graphs show effect of tensile strength as varied by tempering on notch toughness of ferrite-martensite and of martensite (V-notch Charpy results down to —150 F: and strain hardening characteristics of proeutectoid ferrite and of discontinuous phase. Subcritical heat treatments at higher temperatures and longer times appear to embrittle ferrite; embrittlement may not occur during welding but upon extended post heat treatment of weldments. In microstructures of proeutectoid ferrite and martensite (tempered or untempered) microcracks initiate at ferrite grain boundaries and at ferrite-martensite interfaces. Variation of transition temperature with softening of martensite in ferrite-martensite aggregates may be explained on basis of initial hardness variation of ferrite and degree of precipitation of discontinuous structure in deformation of aggregate. Photomicrographs. Work supported by Inco.—INCO. 13878

3.7.4, 6.4.2, 3.8.3

Behavior of Grain and Subgrain Boundaries in Reaction Between Aluminum and Water. (In German.) D. Altenpohl. *Z. Metallkunde*, **48**, No. 5, 306-312 (1957) May.

Formation, composition and aging of Boehmite films are discussed. The investigation, supplementing author's previous work, was carried out by infrared spectrum analysis and differential thermal analysis.—BL. 14582

3.8 Miscellaneous Principles

3.8.4

Electron-Diffraction Study of the Transformation α-Ferric Oxide to γ-Ferric Oxide. G. I. Finch and K. P. Sinha. *Proc. Roy. Soc.*, Sec. A, **241**, No. 1224, 1-8 (1957).

Outgrowths formed on haematite single crystals by heating in air have been examined by electron diffraction. At 500 C a change occurs in their crystal structure, apparently due to the migration of some cations to tetrahedral interstices. Otherwise the unit cell and oxygen-ion framework of the "β-phase" remain as in α-ferric oxide (haematite). At 700 C the structure of the outgrowths changes to one characteristic of γ-ferric oxide and persists as such, even after prolonged heating at 900 C. Thus the transformation γ-ferric oxide to α-ferric oxide is not, as has been supposed, strictly irreversible, since the α-γ transition has now been found to occur under suitable conditions. The presence of β-phase trances seem to be the cause of the anomalous magnetic behavior of haematite observed by Neel and others. It is concluded that the α-γ transformation is a necessary step preceding the solid-state spinelization reaction involved in the formation of a ferrospinel. —RPI. 14625

3.8.4, 3.7.4

The Corrosion of Single Crystals and Recrystallized Single Crystals of Iron and Steel in Citric Acid. W. Roger Buck, III and Henry Leidheiser, Jr. *J. Electrochem. Soc.*, **104**, No. 8, 474-481 (1957) Aug.

Corrosion studies, largely in 0.2M citric acid at 20 C and at the boiling point, were made on polycrystalline disks and monocrystalline spheres and disks of Armco iron and type L steel. Preliminary experiments indicated that the (100) face corroded at the slowest rate and the minor faces, of which the (321) is an example, corroded at the most rapid rate. Quantitative measurements were confined to these two crystal faces. The (100) face was cathodic to the (321) face as shown by potential measurements in 0.2M citric acid in the presence and absence of air. The rate of corrosion of the (321) face was approximately twice that of the (100) face on specimens which were chemically and electrolytically polished, machined with a sharp lathe tool, or polished with emery paper. The rates of corrosion of the polycrystalline starting material from which the single crystals were prepared were several times greater than those of the single crystals. Conversion of the single crystals to polycrystalline material by heating through the transformation temperature resulted in a considerably increased corrosion rate. In the presence of 40-45 ppm of tin (II) the rates of corrosion of the single crystals in 0.2M citric acid at the boiling point were reduced greatly and no significant difference between the (100) and (321) faces was observed.—BTR. 14605

3.8.4, 6.3.6

Fractionation of Oxygen Isotopes in the Formation of Oxide Films on Copper. John B. Brown, Malcolm Dole and G. A. Lane. *J. Chem. Phys.*, **27**, 251-258 (1957) July.

Measurements at 0, 25, and 100 C on granular copper and copper foil by determining the O^{18}/O^{16} isotope ratio in the residual unreacted oxygen gas after a fraction of the oxygen has reacted.—BTR. 14602

3.8.4

Investigations on the Oxidation Mechanism of Single Iron Crystals at High Temperature and Under Low Oxygen Pressure. (In French.) Jean Bardolle. Publ. sci. et tech. ministére air, No. 327, 1957, 622 pp. Available from: Service de Documentation et d'Information Technique de l'Aeronautique, Magazin C.T.O., 2 Av. de la Porte-d'Issy, Paris 15e, France.

Study of the discontinuous superficial growth starting from oxide nuclei, at high temperature and low oxygen pressure. Relations of orientation between the metal and the ferrous oxide. Importance of atomic and ionic density during a chemical reaction on a solid surface.—BTR. 14594

3.8.4, 6.4.2, 6.3.10, 2.3.9

Electrographic Study of Oxide Films Appearing on Aluminum and Nickel Subjected to an Electric Discharge in a Gaseous Oxygen Medium. (In French.) D. V. Ignatov. *J. Chim. Phys.*, **54**, 96-105 (1957) Jan.

Complexity of conditions of formation of an oxide film in a liquid medium and possibility of a secondary reaction between the oxide and the electrolyte impede accurate study of formation of oxide films. Simplified conditions using an electric field during interaction of oxygen on metal were created in an electric discharge tube in a gaseous medium and permitted basic conclusions on mechanism of oxidation of aluminum and nickel. 4 references.—MR. 14676

3.8.4

Oxidation of Barium: A Confirmation of Mott's Theory of Oxidation. R. N. Bloomer. *Nature*, **179**, No. 4557, 493 (1957).

Below 35 C a protective oxide-layer is formed on barium; above 35 C a barium film oxidizes right through. The speed of pumping of oxygen by barium is limited by the superficial ∂ of barium in the oxide. It is concluded that oxidation starts at nucleation centers in the barium surface and then spreads to form a complete monolayer, after which the oxidation proceeds according to the theory of Mott [*Trans. Faraday Soc.*, **43**, 429 (1947)].—MA. 14566

3.8.4, 6.3.20, 3.4.9

Reaction of Zirconium with Water Vapor at Subatmospheric Pressures. M. W. Mallett, W. M. Albrecht and R. E. Bennett. *J. Electrochem. Soc.*, **104**, No. 6, 349-352 (1957) June.

The reaction of iodide zirconium with water vapor at 33 mm Hg pressure was investigated in the range 300-600 C. The rates follow a cubic law. The cubic rate constant in $(\mu g/cm^2)^3/sec$ is $k = 6.71 \times 10^3 \exp(-29{,}700/RT)$ where 29,700 ± 700 cal/mole is the activation energy. Reaction films of monoclinic zirconium dioxide are N-type semiconductors. Therefore, it is concluded that the mechanism of film formation is the same as that for the zirconium-oxygen reaction. 14316

3.8.4

Oxidation of Nickel, Cobalt and Copper at —78, —22, 0 and 26 degrees. J. J. Chessick, U. Yu and A. C. Zettlemoyer. Proc. 2nd Int. Congr. Surface Activity, Lond., 1957, Prepr. 3, DD175-185. *J. Applied Chem.*, **7**, Pt. 5, 367 (1957) May.

Measured rates of oxidation of thin films of reduced nickel, copper and cobalt powders indicate that at each temperature multiple oxide layers form up to 30 Å thick during 100 min., mostly (especially with nickel and cobalt) by a fast, non-activated process. A slow process then commences abruptly, oxygen adsorption being exponential with time. Surface layers of oxide can be regenerated for further oxidation by heating in vacuo. The regeneration is interpreted in terms of formation of metal-lattice vacancies and their elimination by heating, the oxide thickness effectively decreasing during activation. 12 references.—INCO. 14391

3.8.4, 3.2.2, 6.2.3, 4.3.6

Mechanism of Intercrystalline Corrosion in Soft Steel Produced by Ammonium Nitrate. (In French.) M. Smialowski and T. Ostrowska. *Corrosion et Anti-corrosion*, **5**, 76-81 (1957) March.

A study of the effect of ammonium nitrate solutions on iron samples with fine or coarse crystals and under stress. Comparison of the behavior of single and polycrystals. Effect of atmospheric oxygen.—BTR. 14374

3.8.4, 6.3.10
Diffusion of Nickel in Nickel Oxide. Moon Taik Shim and Walter J. Moore. Indiana Univ. *J. Chem. Phys.*, **26**, 802-804 (1957) April.

Diffusion coefficients for nickel in polycrystalline and monocrystalline nickel oxide have been measured by the surface-activity method from 1000 to 1400 C in air. Within experimental uncertainty the values $D = 4.4 \times 10^{-4} \exp(-44.2/RT)$ fit both cases. These results indicate that the oxidation of nickel under comparable conditions of temperature and pressure proceeds via lattice diffusion of nickel through nickel oxide. (auth)—NSA. 14372

3.8.4, 6.3.21, 3.7.4
Rates of Oxidation of Germanium. J. T. Law and P. S. Meigs. *J. Electrochem. Soc.*, **104**, No. 3, 154-159 (1957) March.

Oxidation rates of the (110), (111), and (100) faces of a germanium crystal have been measured between 450 and 700 C and at various oxygen pressures. For all three faces, oxidation rates were inversely dependent on oxygen pressure at and above 550 C, and no differences in behavior between faces were observed. At 500 C only the (110) face oxidized appreciably. A theory has been developed to explain the effect of oxygen pressure on the oxidation rate and calculated values found to be in fair agreement with experiment. 13812

4. CORROSIVE ENVIRONMENTS

4.4 Chemicals, Organic

4.4.2, 6.4.2
Using Aluminum Alloys with Short Chain Aliphatic Acids and Anhydrides. A. B. McKee and W. W. Binger. *Corrosion*, **13**, No. 12, 786t-792t (1957) Dec.

The suitability of aluminum for handling low molecular weight fatty acids and anhydrides for temperatures up to about 50 C has been demonstrated by extensive laboratory tests and confirmed by actual service experience for over 30 years. At the boiling temperature aluminum is highly resistant to acetic, propionic and butyric acids containing from about 0.2 or 0.3 percent to 1 or 2 percent water, but not to solutions containing higher or lower amounts of water. These acids, anhydrides and their mixtures have been processed, stored or shipped in aluminum storage tanks, heating coils, drums, tank cars, piping, valves, stills, heat exchangers and reaction vessels. In addition to excellent resistance to corrosion, aluminum equipment has an added advantage in that it does not contaminate these products nor alter their water-white appearance. 14447

4.4.6, 4.2.3
Deposits and Corrosiveness of Combustible Oils During Combustion: Measurements, Additives. (In Italian.) Maurizio Panetti. *Termotecnica* (Milan), **11**, 127-132 (1957) March.

Ash deposits on metal and non-metallic parts of heating equipment; methods of measuring corrosiveness of residual oils; available corrosion preventives. Attempts to establish, in case of a gas turbine, maximum percentages of harmful elements compatible with proper functioning of equipment: study limited to sodium, vanadium and sulfur. 8 references.—MR. 14776

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4.4.6

Corrosion Studies in Organic Heat-Exchange Media. WALTER K. BOYD, G. LEE ERICSON, OLIVER M. STEWART, PAUL D. MILLER AND ROBERT S. PEOPLES. Battelle Memorial Institute, Columbus, Ohio, Contract Nos. NObs-65057, Jan. 28, 1957, 43 pp.

The corrosion behavior of zirconium base materials, hafnium, high-strength aluminum alloys, and Type 304 stainless steels was studied. Such studies were conducted in isopropyl biphenyl and in biphenyl, with and without additions of water and hydrogen, over the temperature range 600 to 800 F. The materials were evaluated on the basis of weight gain, changes in bend ductility, and metallographic examination of the samples after exposure to the selected test conditions. Two types of attack were found: oxidation from water in the organic fluids, and hydriding from hydrogen which was added or was generated by decomposition of the organic material. Corrosion or the formation of an oxide film on the structural materials was found to be a function of the water content of the organic compound. Unalloyed crystal-bar zirconium, Zircaloy 2, and Zircaloy 3A were quite resistant to biphenyl at 800 F and to isopropyl biphenyl at 700 F when the water content of the organics did not exceed 200 ppm. On the other hand these materials were severely attacked at 800 F by biphenyl containing 400 ppm water. At 700 F in isopropyl biphenyl containing 3400 ppm water, all the zirconium-base materials with exception of Zircaloy 2 exhibited heavy coatings of corrosion product and high weight gains. Type 304 stainless steel and hafnium had excellent corrosion resistance under all test conditions at 600, 700, and 800 F, while the aluminum alloys showed moderate attack at 700 F in isopropyl biphenyl containing 3400 ppm water. The major limiting factor in the use of zirconium-base materials in the organics is hydrogen embrittlement. At temperatures of 700 F and above, additions of hydrogen result in severe embrittlement of the zirconium-base materials. Embrittlement of the aluminum alloys and Type 304 stainless steel was not observed in any of the tests. Pretreatments of zirconium-base materials consisting of an 18 hr. exposure in 750 F steam or anodizing in 70 percent nitric acid were effective in reducing hydrogen absorption. However, these treatments did not prevent embrittlement after extended exposure periods. (auth.)—NSA. 14538

4.4.8, 6.2.3, 3.2.3

The Corrosion of Mild Steel by Aqueous Ammonium Thiocyanate. L. A. RAVALD, J. W. CHILVER AND R. WILLIAMS. *J. Applied Chem.*, **7**, 113-117 (1957) Mach.

The pH range for localized attack was wider with the more dilute solutions. Solid corrosion products were mixtures of black iron ferrocyanide and a ferrous sulfide. At 90 C in an oxygen-free atmosphere, corrosion was more severe than with ammonium chloride.—BTR. 14342

4.4.7, 3.4.2

The Catalytic Effect of Metals on the Corrosiveness of Motor Oils. A. V. DRUZHININA AND G. S. TARMANYAN. *Khimiya i Tekhnologiya Topliva i Masel (Chemistry and Technology of Fuel and Oils)*, No. 7, 43-49 (1957) July.

Susceptibility of lead, copper and indium to corrosion was studied. Lead was found to be most susceptible to corrosion by the products of oxidation of residual and distillate oils. Relationship between catalytic action of copper on oxidizability of oils and corrosiveness of oils with respect to lead and lead and indium bearing plates is established. 5 tables, 3 figures, 4 references. —ATS. (Translation available: Associated Technical Services, P. O. Box 271, East Orange, New Jersey.) 14650

4.5.3, 1.7.3

A Concentrator for Coordinated Corrosion Testing. A Contribution to the Work of NACE Technical Unit Committee T-4B on Corrosion of Cable Sheaths. Oliver Henderson and Louis Horvath. *Corrosion*, **13**, No. 12, 799t-802t (1957) Dec.

A concentrator for coordinated corrosion testing is described with which 19 simultaneous voltage readings can be made and which requires only one suitable voltmeter.

The test box contains nineteen 4 mf capacitors, each of which accepts a charge from one of the external test circuits. At the desired instant of testing, the external circuits are all disconnected from the capacitors by the opening of gang-type relays. The voltage standing on each capacitor is then the corresponding voltage of the particular external circuit at the instant of disconnection. By means of a rotary switch, these voltages can be taken off in sequence and read out on a suitable external voltmeter at the convenience of the observer.

The advantages derived from the use of the test box are as follows: 1) One meter observer can duplicate the work of up to nineteen observers on a meter-per-circuit basis; 2) One accurate voltmeter, having a high input impedance, can be selected for use rather than using an assemblage of 19 meters; 3) Despite fluctuation in measured voltages, the data obtained are more accurate than ordinarily can be obtained by direct readings of a meter on a test circuit; 4) The readings are truly simultaneous; 5) The use of one observer and one meter avoids variances formerly introduced by human characteristics and meter dissimilarities. 14453

4.6 Water and Steam

4.6.2

Boiler Feed Water Treatment for Advanced Steaming Conditions. J. LEICESTER. *Trans. Inst. Marine Engrs.*, **69**, No. 4, 129-136 (1957) April; *Corrosion Prevention and Control*, **4**, No. 6, 53-58 (1957) June.

The modern trend towards the operation of boilers at higher steam pressures and temperatures arises from the desire of both turbine and boiler designers to secure increased thermal efficiencies. Of paramount importance to marine engineers is the power/weight ratio of such steam raising plant and its effect upon the overall design of ships' machinery and economy of operation of the complete machinery installation. To obtain such performance has necessitated continued research into the fundamentals of the steam generation process.

The higher operating pressures and steam temperatures, also the higher rates of heat absorption in the furnace wall tubes, obviously intensify the many problems associated with long periods of continuous steaming. Hence improved methods of feed water treatment promise to be of major importance in improving the operational life of marine boiler plant. It is the purpose of the present paper to compare and discuss recent trends in feed water treatment and testing techniques.—TIME. 14321

4.6.4, 7.4.1

Corrosion Problems in a Blast Furnace Water-Cooling System. H. B. LLOYD. *Corrosion Technology*, **4**, No. 7, 221-224 (1957) July.

Describes techniques and designs employed to provide practical solution to corrosion problems of blast furnace water-cooling system based on soft water supply. Water-cooling system, external pipework and stave coolers are discussed. Conventional design has copper cooling elements connected with mild steel pipe in conjunction with malleable iron elbows. Data are presented which show that rate of flow for cooling water of 20-ft. hearth diameter furnace was reduced by 66 percent in 5 years due to blockage by corrosion products from iron-to-copper junction. Results with copper tubing joined by asbestos covered rubber hose showed no blocking; cost of screwed copper connections is prohibitive. Corrosion preventive design on stave coolers has straight mild steel pipes cast into cooler and copper tube inserted. On coolers below tapping hole and slag notch, pure nickel tubes 2-in diam 12 gauge were cast in. Steel sleeve screwed externally to 2-in B.S.P. thread was bored out to fit over end of nickel tube and welded to it at outer end prior to casting. Screwed connection provided copper-nickel junction with external copper pipework, so that water makes no contact with cast iron or steel. —INCO. 14683

4.6.4, 5.8.2

Inhibiting a Cooling Water Tower System. F. L. WHITNEY, JR. *Corrosion*, **13**, No. 11, 711t-718t (1957) Nov.

When recirculating cooling tower systems are used as a source of cooling water for plant operations, quality and composition of the initial and make-up water systems are not the only factors to be considered when selecting an inhibitor. Also important are the contaminating factors introduced from the atmosphere.

This paper describes a situation wherein at one plant the initial inhibitor treatment became ineffective due to expansion of plant activities and introduction of additional and greater amounts of atmospheric contamination. The value of laboratory screening tests followed by plant tests to assure proper protection are discussed. As a result of this incident the value of continuous testing in the field in a versatile and ever-growing plant is reported. 14403

4.6.4, 5.8.1

Non-Chemical Factors Affecting Inhibitor Selection and Performance in Air Conditioning Cooling Waters. SIDNEY SUSSMAN. *Corrosion*, **13**, No. 11, 701t-710t (1957) Nov.

The rapid growth of air conditioning, particularly in urban areas, has multiplied cooling water corrosion problems. The effectiveness of corrosion control by chemical inhibitors in these systems is subject to non-chemical factors to a degree not usually encountered in the larger industrial cooling systems. These considerations include economic, me-

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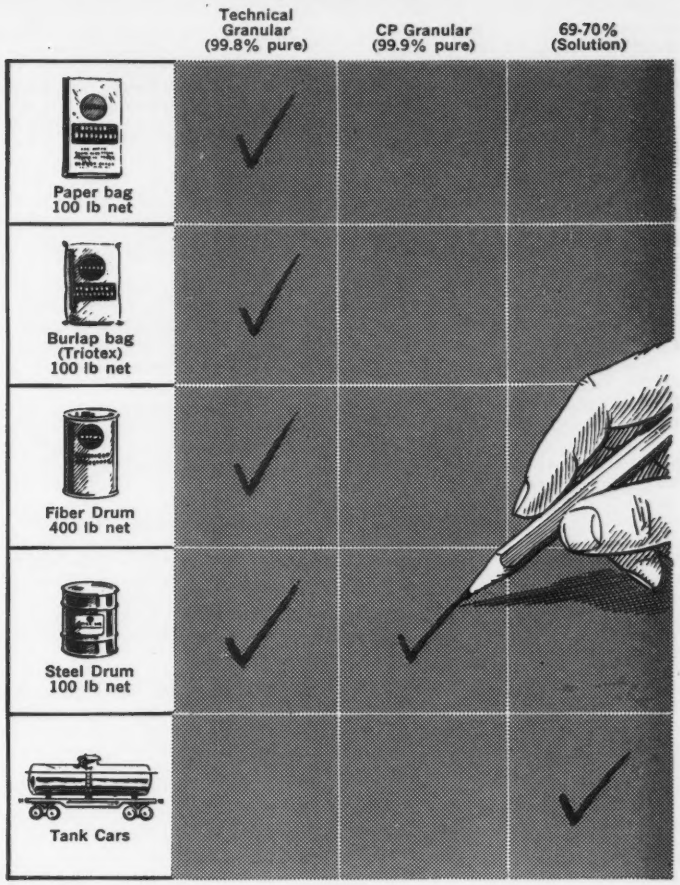
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chanical, human and legal factors. The use of untrained personnel for equipment operation and maintenance can restrict the choice of inhibitor or negate an otherwise satisfactory corrosion control program, as well as increase safety hazards.

Selection of the inhibitor and its use are restricted in many cases by legal requirements pertaining to cross-connections, water conservation, or waste disposal. Equipment location, rarely considered from the viewpoint of maintenance and corrosion control, is frequently a factor in the choice of inhibitor and in its effectiveness. Attempts to keep equipment and operating costs low frequently have secondary effects upon corrosion control. 14405

4.6.4, 5.8.2

Factors Other Than Mineral Content Which Influence the Corrosiveness of Cooling Water. E. H. Hurst. *Corrosion,* **13,** No. 11, 696t-700t (1957) Nov.

There are several factors other than mineral constituents which determine the corrosiveness of a cooling water. These factors include microbiological activity, silt and debris, suspended solids, dissimilar metals and hydrocarbon pollution. The complete effective performance of a cooling water corrosion prevention program cannot be realized without controlling these factors. Data are given to show the effect of summer and winter slime on corrosion rates in the presence of an inhibitor. 14419

4.6.4, 2.3.4, 3.6.6, 5.8.1

An Evaluation of Inhibitors for Corrosion Prevention in an Engine Cooling System. Leonard C. Rowe. *Corrosion,* **13,** No. 11, 750t-756t (1957) Nov.

The variation of coolants used in a multi-metal engine cooling system offers a challenge for corrosion inhibition. The diverse characteristics of this system are discussed along with their relationship to the selection of laboratory test methods to investigate inhibition.

A rotating specimen type of test is used for the evaluation. The effectiveness of inhibitors, such as sodium borate, sodium nitrite, sodium benzoate, potassium dichromate, soluble oil, and sodium mercaptobenzothiazole, is compared by means of this test. Various test media are used, including ethylene glycol-water mixtures and tap water with and without additional corrosive constituents. The metals investigated are steel, copper, brass, aluminum, cast iron and solder. The results are based on corrosion rate, microscopic examination, pit depth when applicable, and other general examinations. This work includes the results of one year static room temperature tests on thirteen galvanic couple combinations for each inhibitor.

Based on the results obtained by conventional corrosion tests, a final examination of a combination of inhibitors is made in a laboratory model which simulates an engine cooling system. This test indicates effective inhibition by this combination in a system using either a copper-brass or aluminum radiator. 14431

4.6.11, 6.6.11, 6.6.5, 7.10

Jackets of Creosoted Wood Protect Concrete Piles. R. H. Mann. Am. Wood Preservers Inst. *Eng. News-Record,* **158,** No. 7, 41 (1957) Feb. 14.

Deterioration of precast concreted piles in tide waters in and adjacent to New York City was prevented for periods ranging up to 33 years by means of placement of pressure creosoted wood jackets in tide zone. In contrast to this, in a structure comprising about 1,000 unprotected piles in same tide waters, over 970 required extensive and costly repairs. Lumber of jackets was pressure-creosoted to protect it against decay in above-water and in alternately wet-and-dry area in tide zone and to protect it against activities of marine wood borers which infest waters. For such protection, heavy absorptions of coal tar creosote are mandatory since no important structural species of wood grown in U. S. can resist marine borer attacks when installed in an untreated condition. Photos. —INCO. 14795

4.7 Molten Metals and Fused Compounds

4.7, 3.5.4, 6.2.2

Stability of Iron Toward Lithium at Elevated Temperatures Under Cyclotron Irradiation. W. W. Parkinson, Jr. North American Aviation Inc. U. S. Atomic Energy Comm. Pubn., NAA-SR-73, Aug. 27, 1952 (Declassified March 8, 1957), 47 pp. Available from Office of Technical Services, Washington, D. C.

Iron capsules containing lithium were irradiated at temperatures of 625 C and 910 C, with the direct α beam of the Berkeley 60-in. cyclotron, to investigate radiation-induced corrosion. Chemical analysis of the lithium charge showed no increase in corrosion at 625 C and indicated that there probably was little effect on corrosion at 910 C. Metallographic and X-ray studies carried out on the iron specimens indicated only slight structural changes, if any, attributable to irradiation at either temperature. (auth.)—NSA. 14747

4.7, 6.6.4

The Action of Molten Uranium on Graphite. E. L. Swarts. Knolls Atomic Power Lab. U. S. Atomic Energy Comm. Pubn., KAPL-1765, April 9, 1957, 23 pp. Available from Office of Technical Services, Washington, D. C.

An approach was developed for studying the long-term interaction between molten uranium and graphite in the temperature range 1150 to 1400 C. Preliminary results indicate that in this system an adherent, protective carbide coating forms on the graphite at a rate strongly dependent upon the temperature. (auth.)—NSA. 14820

4.7, 1.2.5

Handling Techniques for Rubidium. H. E. McCoy, Jr. and E. E. Hoffman. Oak Ridge National Lab. U. S. Atomic Energy Comm. Pubn., ORNL-1991, Dec. 12, 1955 (Declassified March 1, 1957), 15 pp. Available from Office of Technical Services, Washington, D. C.

Procedures are outlined for opening rubidium containers received from suppliers, distillation and filtration of rubidium, and loading liquid rubidium in corrosion-testing systems. The corrosive effects of liquid rubidium on Inconel at elevated temperatures (~1500 F) were investigated. Physical properties of rubidium are tabulated.—NSA. 14816

4.7, 6.2.5, 6.3.10

Metallurgical Investigations of Sodium Heat Transfer Rig. A. G. Ward and J. W. Taylor. Great Britain Atomic Energy Res. Establishment, Harwell Berks, England, Rept. M/M-148, Feb., 1957, 18 pp.

A study was made of the attack of stainless steel and nickel by sodium, both oxygen-free and contaminated, at temperatures in the range 300 to 600 C in static and dynamic tests. A number of miscellaneous metallurgical investigations on components taken from a stainless steel/nickel double annulus heat exchange rig are also reported. Under the conditions of test, stainless steel of the 18 wt. percent chromium-8 wt. percent nickel containing free carbide, undergoes considerable attack, both in static and dynamic tests in sodium nominally free from and also heavily contaminated with oxygen. From the evidence available it is suggested that the mode of attack consists of a decarburizing action which proceeds intergranularly and modifies the spheroidal carbide in the affected region by diffusion of this phase into the matrix. Under similar test conditions nickel undergoes no detectable corrosion even at the highest temperature. It is recommended that prior inspection be carried out on stainless steel for use in systems containing sodium at temperatures above 300 C, to ensure that the steel specification has been fulfilled and that the material is devoid of free carbide. (auth.)—NSA. 14821

4.7

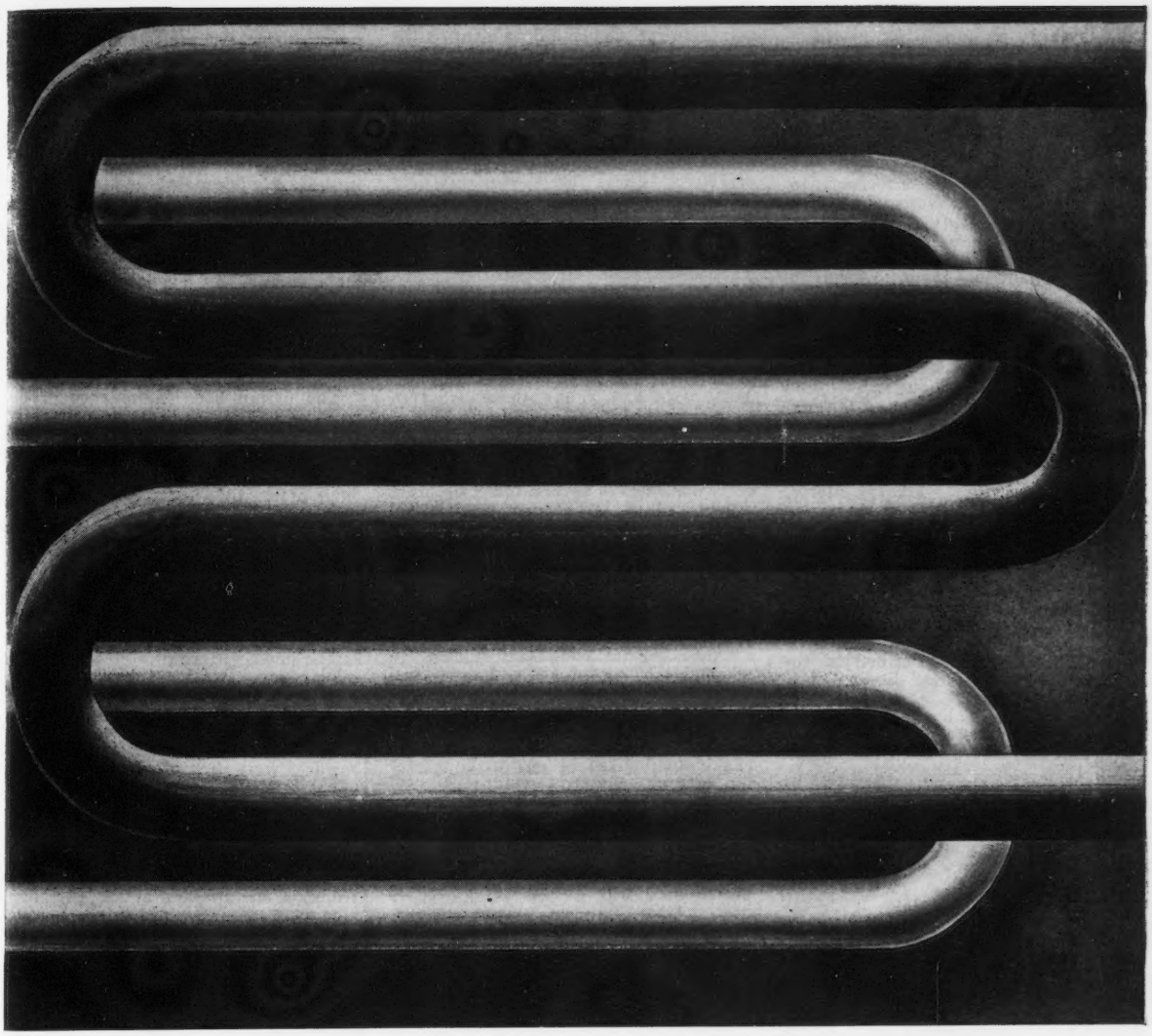
Static and Dynamic Corrosion and Mass Transfer in Liquid Metal Systems. Leo F. Epstein. Knolls Atomic Power Lab. *Chem. Eng. Progress,* **53,** Symposium Ser. No. 20, 67-81 (1957).

In many systems involving liquid metals, the principal mechanism of corrosion of a solid exposed to the fluid is simple solution. In a static isothermal assembly the rate of corrosive attack is determined by the classical theory involving the solution rate constant α. The value of this parameter depends on whether the rate-determining step is 1) the diffusion of the solute through the liquid or 2) transfer of the solute through a solid film or some product of chemical reaction at the solid-liquid interface. In dynamic corrosion, such as is encountered in heat transfer loops, where parts of the system are at different temperatures and the fluid flows continually from the hot to the cold zone, different expressions are obtained for the corrosion rate depending on whether mechanism 1 or 2 is more important. These results are examined for a few solid-liquid metal systems, and quantitative relations capable of yielding order-of-magnitude agreement with experiment are obtained. The material dissolved in the hot zone of a heat transfer loop tends to deposit out of solution in the cold zone, resulting in an over-all transport of material. Factors influencing this mass transfer rate are examined. The effects of minor impurities in the solvent in accelerating and inhibiting corrosion are discussed. (auth.)—NSA. 14606

4.7, 5.3.4, 8.8.5

The Attack of Molten Zinc Containing Cadminum on Iron. (In German.) D. Horstmann. *Arch. Eisenhuttenw.,* **28,** No. 4, 195-199 (1957) April.

Experiments showed that the attack of zinc on iron is increased by the presence of up to 10 percent cadmium. The temperature range in which the attack is accentuated and proceeds linearly is extended, particularly downwards. The rate of parabolic attack at temperatures below and above the critical 'linear' range is determined by the rate of diffusion through the Γ-layer; the occurrence of linear attack is due to the break-up of the Γ-layer. Determination



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of iron loss. Growth of the iron-zinc alloy layers. 14693

4.7, 6.3.20

Effect of Sodium on the Mechanical Properties of Zirconium. J. C. BOKROS. Atomics International Div., North American Aviation, Inc. U. S. Atomic Energy Commission Pubn., NAA-SR-1867, June 15, 1957, 39 pp. Available from Office of Technical Services, Washington, D. C.

Zirconium is useful as a structural material in nuclear reactors, and is employed in contact with high temperature liquid sodium. It was found that surface oxide which develops on zirconium in sodium significantly lowers the fatigue life at elevated temperatures. Hydrogen on the other hand has very little effect on the fatigue life at elevated temperatures but lowers the fatigue life at room temperature. It was also found that exaggerated grain growth which occurs above 950 F in zirconium severely reduces the fatigue life at elevated as well as low temperatures. The effect of sodium, i.e., the pick-up of surface oxide and reasonable amounts of hydrogen, does not significantly alter the tensile properties of zirconium at high temperature. Data also indicate that zirconium is stable to dimensional changes after thermal cycling. (auth.)—NSA. 14552

4.7, 6.3.10

Two-Phase Product Formed in the Reaction Between Fused Sodium Hydroxide and Inconel. G. P. SMITH, M. E. STEIDLITZ AND E. E. HOFFMAN. Oak Ridge National Laboratory. U. S. Atomic Energy Commission Pubn., ORNL-2129, April, 1957, 15 pp.

Reaction consisted of the selective leaching of iron and chromium from their solid solution with nickel. The reaction product, a mixture of oxides and sodium oxysalts, grew in a network of narrow channels which, starting from the hydroxide-metal interface, penetrated along preferred paths into the underlying Inconel.—BTR. 14378

4.7, 3.7.3

Sodium Corrosion and Oxidation Resistance of High-Temperature Brazing Alloys. G. M. SLAUGHTER, C. F. LEITTEN, JR., P. PATRIARCA, P. HOFFMAN AND W. D. MANLY. Oak Ridge Nat'l. Lab. *Welding J.*, **36**, No. 5, 217s-225s (1957) May.

Summary of sodium corrosion and oxidation tests of high temperature brazing alloys developed for use in fabrication of high-temperature heat exchanger equipment. Specimens were T-joints of "A" nickel, Inconel, Type 304 and Type 310. Tests in sodium were conducted at 1500 F while oxidation tests were run at 1500 and 1700 F. Majority of alloys tested were nickel-base. Alloys of systems of nickel-silicon-boron, nickel-chromium-silicon-boron and nickel-chromium-silicon types were found to be compatible in both media. Precious-metal alloys (palladium and gold) were severely attacked by sodium, as were many of the silicon-free, chromium-free, phosphorus-bearing alloys. Alloys containing manganese exhibited poor resistance to oxidation at 1500 F. In most cases, oxidation was more pronounced at 1700 F. Tables, photomicrographs.—INCO. 14367

4.7, 8.8.5

Contribution to the Problem of the Life of Lead Bath Pots. H. KRAUTMACHER AND W. PUNGEL. *Stahl und Eisen*, **77**, No. 13, 837-844; disc., 844-845 (1957) June 27.

Reviews former findings, preliminary tests and test practice, and discusses corrosion rate as being dependent on the annealing time and temperature. Effect of condition of material is considered. Killed Siemens-Martin steels were more resistant to lead attack than un-killed Siemens-Martin steel. This was confirmed in service tests at annealing time of 300 hours and annealing temperature of 720 C. It was also shown that heat resistant chromium and chromium-nickel steels had unusually high resistance to corrosion attack by lead. Tables, graphs, photomicrographs.—INCO. 14350

4.7

Corrosion of Several Materials in the Fused Alkaline Salt (the Mixture of Sodium Hydroxide-Sodium Bromide-Sodium Iodide) and Sodium Amalgam at Higher Temperature. S. OKADA, S. YOSHIZAWA AND N. WATANABE. *J. Chem. Soc. Japan*, Ind. Chem. Section, **60**, No. 6, 675-676 (1957) June.

In order to select the materials for metallic sodium cell in amalgam process, corrosion rates of several materials were determined. It is supposed that nickel and iron are not attacked by these corrosive liquids at room temperature, so corrosion of these metals was examined at higher temperature. Next, non-metallic materials, for flange packing, stuffing box and so on, and then metals, which were coated with protecting film on their surface were also studied. In alkaline salt, nickel and stainless steel were scarcely attacked. The corrosion of mild steel was relatively vigorous, but that with the film of iron phosphate on its surface greatly decreased and any change of the surface was not found for ten hours. Such Parkerized mild steel may be one of the materials suitable for industrial use. It was found that sintered alumina was attacked less and most available for the small scale experiment. Most of the silicates were decomposed with alkali and dissolved in the fused salts as sodium silicates. Rubberized asbestos, Kel-F and Teflon resins could serve as insulator, but were gotten out of shape in the long run at higher temperature.

On the other hand, nickel and iron, which are not attacked by sodium amalgam at room temperature, dissolved in amalgam at higher temperature, and so the amalgam was contaminated with these metals. This effect increased generally with temperature and also with amalgam concentration. The formation of iron phosphate film retarded this effect as in the fused alkaline electrolyte, and so it is considered that iron phosphate coating of all parts of electrolytic cell is very effective in inhibiting corrosion.—JSPS. 14348

5. PREVENTIVE MEASURES

5.2 Cathodic Protection

5.2.1

A Study of Current Distribution in Cathodic Protection. E. E. NELSON. U. S. Naval Research Laboratory, Report 4868, Jan., 1957, 11 pp.

Effects of solution resistance and cathodic polarization. Advantages of good paint coatings.—BTR. 13794

5.2.1, 3.6.5

Cathodic Protection Handbook. O. OSBORN, C. F. SCHRIEBER, W. B. BROOKS, R. C. JORGENSEN AND D. DOUGLAS. Dow Chemical Co. *Petroleum Refiner*, **36**, No. 6, 115-128 (1957) June.

Fundamentals of cathodic protection and techniques of field measurement are given. Table gives electromotive series of materials including Ni-Resist, stainless steel, nickel, Hastelloy and Monel. Galvanic protection of condenser and heat exchanger heads is described. Galvanic series given of metals and alloys in 13 foot per second sea water at 25 C includes copper-nickel and Monel. Cathodic protection of miscellaneous marine equipment and underground pipe lines is described and economics of cathodic protection are considered. Photos, tables, graphs, diagrams.—INCO. 1433

5.2.1, 7.2

Properly Placed Anodes Protect Station Piping. R. G. RANSOM. *Pipe Line Ind.*, **6**, No. 3, 20-23 (1957) March.

The design and maintenance of distributed anode systems for corrosion protection of compressor station piping is discussed. 1433

5.2.1, 4.6.11, 7.5.5

A Trial on Cathodic Protection of Sea-Water Tank. Pt. II. On the Combination of Electrocoating by the Current from External Source and High-Purity Zinc Anodes. (In Japanese.) H. SHIGENO, Y. HISAMATSU, I. KOIZUMI AND T. SODA. *Corrosion Engineering*, **6**, No. 1, 40-43 (1957) Jan.

The inner surface of a steel tank containing sea-water was electrocoated by electricity from external source, under the condition of the current of 1 ampere and 50 ampere-hour per square meter of protected area respectively. The coated surfaces were then protected with high-purity zinc anodes for about 2000 hours. The coating obtained was found to be so excellent that the necessary current to maintain the protective potential was about 5-10 milli-ampere per square meter of steel surface. The potential distribution on tank and anodic current of zinc were frequently measured. Through the test, the high-purity zinc anodes held a more negative potential than —1.0 volt referred to satd. calomel and even reached anode efficiency of 94 percent.—JSPS. 14361

5.2.1, 8.9.5

Marine Cathodic Protection. A. J. WHITEHEAD. *Corrosion Prevention & Control*, **4**, No. 6, 59-60 (1957) June.

Discusses formation of pits and corrosion products in oil tankers. Oil film, due to its ohmic resistance, will reduce galvanic action, but, where film is broken, additional corrosion currents are set up which intensify local anodic corrosion rate. With installation of anodes to produce high intensity current, previous corrosion products in form of scale are removed, calcareous film is formed, and current requirements drop. Installation using finned anodes (designed for 4-year service), and an impressed current scheme, using silicon iron anodes, are described.—INCO. 14841

5.2.2, 8.9.3

'Built-In' Anodes Protect Submarine Line. A. L. STEGNER AND J. B. BAXTER. *Pipe Line Industry*, **7**, No. 3, 28-31 (1957) Sept.

Installation of zinc anodes to protect the center 10 miles of a 21-mile submarine line is described. The anode rings are designed to be flush with the concrete weight coat which is applied later and are expected to provide 40 year protection without maintenance. 1476

5.2.2
The Current—Voltage Relationship of Galvanic Anode Arrays in Cathodic Protection. L. J. WALDRON AND M. H. PETERSON. U. S. Naval Research Laboratory, Report 4891, Feb., 1957, 17 pp.—BTR. 14390

5.2.2, 8.9.5
Cathodic Protection of Ship Hulls. Pt. II. Results Obtained with Magnesium Anodes. (In Japanese.) M. SEO. *Corrosion Engineering*, **6**, No. 3, 36-39 (1957) May.

Experiments on cathodic protection with magnesium anodes have been carried out using tug boats, Daiichi-Tetsuei-maru and Hiyama-maru. In the magnesium anodes system it was found to be difficult to control the anode current, especially an over-current occurred frequently. Therefore, the paint coats were damaged and the consumption of the magnesium anode was accelerated. —JSPS. 14366

5.2.3
An Automatic Regulator for Cathodic Protection of Pipe Lines. (In Russian.) V. I. IVANENKO AND A. D. PUSHCHALOVSKII. *Avtomatika Akad. Nauk, Ukr. S.S.R.*, No. 1, 18-26 (1957) March 20.

A constant potential may be attained only with the aid of an automatic regulator which continuously changes the resistance of the current circuit. The use of a thermogenerator as the source of direct current is recommended.—BTR. 14678

5.2.4, 8.4.3, 2.3.5
Current Requirement for Cathodic Protection of Oil Well Casing. E. W. HAYCOCK. *Corrosion*, **13**, No. 11, 767t-774t (1957) Nov.

Methods at present used to indicate the minimum applied current required to give complete cathodic protection are discussed and evaluated in terms of their scientific basis and their applicability to the protection of oil well casing. Laboratory experiments are described involving the application of cathodic protection currents to a series assembly of galvanic cells. The results of these experiments lead to a modification of the log current—potential criterion of complete protection widely used at the present time. The experiments also indicate the amount of corrosion repressed as a function of the applied protection current, information which is of considerable value when an economic balance is involved. 14433

5.3 Metallic Coatings

5.3.4, 3.2.2, 2.3.7
Designed Properties of High-Strength Steels in the Presence of Stress Concentrations and Hydrogen Embrittlement. Pt. 3. The Response of High-Strength Steels in the Range of 180,000-300,000 psi to Hydrogen Embrittlement from Cadmium Electroplating. E. P. KLIER, B. B. MUVDI AND G. SACHS. Syracuse University. U. S. Wright Air Development Center, Tech. Rept. 56-395, Part 3, March, 1957, 129 pp. Available from Office of Technical Services, U. S. Dept. of Commerce, Washington, D. C. (Order PB 131034).

Embrittlement of high strength steel from the action of hydrogen introduced by cadmium electroplating was studied in sustained-load, rotating beam fatigue, and bending tests. Among the observations, it was found that all steels are embrittled in some measure after cadmium plating. Baking treatments remove some of the embrittlement, an improvement promoted by redistribution rather than elimination of hydrogen from the steel. The observation that failure promoted by plating is affected by experimental conditions is discussed at length. Cracking in the hydrogen bearing zone seemed dependent, in part, on composition and is minimized by reduction in carbon or increase in silicon. Sustained-load and bend tests were shown suitable for embrittlement evaluation in ultra high-strength steels. The rotating beam fatigue test is relatively

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insensitive to embrittlement, but is an excellent measure of the "static" notch strength of steel, according to the report.—OTS. 14667

5.3.4

The Sherardizing Process: Influence of Part Shape on the Depth of the Sherardized Coatings and on Their Corrosion Resistance. (In Italian.) L. MATTEOLI AND F. BARIGOZZI. *Metallurgia Italiana,* **49,** No. 5, 355-362 (1957) May.

An experimental sherardizing drum 8 in. in diameter and 14 in. long was used to study factors affecting the coatings formed on hollow and tubular parts. The importance of using a sherardizing mixture that does not easily coalesce is emphasized; the best results were found when the mixture contained coarse zinc dust (0.2-1 mm) and fine dust (25-40μ) together with 10 percent wood charcoal and 10 percent sand. Charcoal was more effective than sand in preventing coalescing, but more than 10 percent made the coating too dark. Coating weights inside and outside tubes are tabulated; generally the outside coating was about twice as heavy as the inside. The results of salt spray tests are also described. Different methods of surface preparation of steel for sherardizing are now being studied.—ZDA. 14731

5.3.4, 6.3.17

Surface Alloying of Uranium. H. A. SALLER, J. R. KEELER AND E. S. HODGE. Battelle Memorial Institute. U. S. Atomic Energy Comm. Pubn., BMI-895, Jan. 5, 1954 (Declassified Feb. 26, 1957), 18 pp. Available from Office of Technical Services, Washington, D. C.

Several methods of producing a surface layer of corrosion-resistant alloy on uranium were investigated. Cementation of metal powders of zirconium, molybdenum, niobium, nickel, iron, or chromium on uranium produced spotty coatings which were rough and tested erratically in boiling water. Reduction of zirconium hydride on uranium strip resulted in a porous metallic coating, and metallic additions to the zirconium hydride failed to reduce substantially the porosity of the coatings. Other methods of surface alloying, such as formation of the hydride "in situ" with subsequent reduction, and miscellaneous techniques resulted in coatings less desirable than those obtained by cementation or by reduction of zirconium hydride. (auth.)—NSA. 14773

5.4 Non-Metallic Coatings and Paints

5.4.2, 6.6.5, 6.2.2

Anodic Corrosion of Iron in Reinforced Concrete. (In Italian.) MARIO MARAGHINI AND CESARE GINNAR. *Ricerca Scientifica,* **27,** 1500-1508 (1957) May.

Iron bars were coated with different types of cement mortar and seasoned 7 to 9 months. Spontaneous corrosion during seasoning was slight and did not interfere with results of tests for anodic corrosion. Variations in quantity of electricity passed through specimens caused marked differences in corrosion, possibly due to nature of cements and presence of chlorides. Variations of current density caused a minimum of variation in corrosion, suggesting a relationship between protective action of cement and its capacity to oppose local variations of pH. Measurement of difference of potential applied to system in function of time permitted determination of phenomena accompanying cracking of cement coatings.—MR. 14813

5.4.2, 2.2.2

Fifteen Year Exposure Test of Porcelain Enamels. D. G. MOORE AND W. N. HARRISON. U. S. Dept. of Commerce, Nat. Bur. Standards, Building Materials & Structures Rept. No. 148, June 28, 1957, 13 pp.

Weather resistance of 768 panels representing 14 types of enamel was evaluated after 15 years exposure at Washington, D. C., St. Louis, Mo., Lakeland, Fla., and Atlantic City, N. J. Changes in gloss and color were taken as criteria of weather resistance. Direct relation existed between acid resistance and weather resistance, except that a few of red enamels of good acid resistance showed pronounced fading after exposure. Modified acid (boiling nitric acid) test was devised that separated red enamels that tend to fade from these highly resistant to color change. Results of boiling nitric acid test are given in mg/cm^2. Ease of cleaning was related to weather resistance. All of the enamels protected steel from corrosion when initial coverage was complete. Tables, graphs.—INCO. 14331

5.4.2

Characteristics of Refractory Oxide Coatings Produced by Flame Spraying. N. N. AULT. Paper before Am. Soc., 58th Ann. Mtg. New York, April 23, 1956. *J. Am. Ceram. Soc.,* **40,** No. 3, 69-74 (1957) March 1.

Description of techniques and methods of application of flame-spraying of ceramic materials. Discussion of properties of materials includes reference to cobaltous oxide rods. Phases present, density, porosity, thermal expansion, thermal stability and mechanical properties are given for coatings made from rods of alumina, zirconia and zircon on stainless steel. Photomicrographs, graphs.—INCO. 13787

5.4.5

Current Views on How Paint Films Prevent Corrosion. J. E. O. MAYNE. *J. Oil and Colour Chemists' Assoc.,* **40,** 183-199 (1957) March.

Mechanism of the corrosion of iron and steel and the arguments which led to the conclusion that protection is associated with a high electrical resistance; the effect of ions on this resistance is considered. The ions may be underneath the paint film and consequently short-circuit the high resistance or they may occur outside the film and bring about a decrease in resistance by diffusing into the film.—MR. 13784

5.4.5

Fluidized Plastic Coatings for Corrosion Resistance. J. A. NEUMANN AND F. J. BOCKHOFF. *Product Eng.,* **28,** No. 1, 140-143 (1957) Jan.

Powder dip process provides uniform corrosion-resistant coatings on intricate parts. Parts to be coated are heated to melting range of plastic, then immersed in bed of specially prepared plastic powder, maintained in fluidized condition by compressed air or inert gas. Upon removal, residual heat melts and levels adhering powder particles to smooth, non-porous resin coat. Mechanism of fluidization, coatings available, cost factors, and applications are discussed. Table presents data on corrosion resistance of fluidized polyethylene coating in sulfuric, nitric, hydrochloric, phosphoric, chromic, formic, citric and lactic acids, and caustic soda.—INCO. 13819

5.4.5

Structure, Characteristics and Uses of Urethane Coatings. RICHARD C. BURCK. *Corrosion,* **13,** No. 12, 130, 132, 138 (1957) Dec.

Molecular configuration of the isocyanate polymers is given, together with a brief explanation of the linkages which give the coatings and materials derived from them their properties. Examples are related and illustrated of successful service use of urethanes in Germany. Results of laboratory tests versus competitive high grade coatings submerged in water and subjected to several chemicals are described and illustrated.

A new isocyanate adduct containing less than one percent of the irritating free tolylene diisocyanate monomer is being produced. This material is improved to the extent that no precautions not presently used in handling coatings containing solvents are required. Presented under the title "Urethane Coatings" at the 13th Annual Conference, National Association of Corrosion Engineers, St. Louis, Mo., March 11-15, 1957. 14441

5.4.5

Some Keys to Successful Industrial Contract Painting. L. L. SLINE. *Corrosion,* **13,** No. 12, 134, 136, 138 (1957) Dec.

Successful use of the services of an industrial contract painter involves establishment of a painting program, compilation of specifications, a bidding procedure which gives all an equal chance to get the work, care in selecting a responsible contractor, thorough inspection to assure specifications are met. Manufacturers are advised to keep sales people informed adequately on technical matters, provide application instructions to the men doing the actual work, and have technical representatives inspect jobs in progress to check on failure to follow recommendations. The contractor should be willing to stay abreast of new equipment and materials, train his workmen properly and provide competent field supervision. Condensation of a paper presented under title "An Industrial Painting Contractor Sounds Off" at the 13th Annual Conference, National Association of Corrosion Engineers, St. Louis, Missouri, March 11-15, 1957. 14442

5.4.5

Observations and Experimental Findings on the Influence of the Surface Preparation of the Steel on the Behavior of Zinc-Rich Paints. (In Italian.) G. BINETTI AND G. C. GHISOLFI. *Metallurgia Italiana,* **49,** No. 5, 327-332 (1957) May.

After an analysis of the process of rusting, the authors describe tests made in the laboratory and by actual exposure, to determine the effectiveness of zinc-rich paints applied to steel samples prepared in different ways. The laboratory experiments showed the necessity of removing as much rust as possible. If the paint is applied to a partially scaled surface, it will peel from regions at the boundaries of the scale while remaining intact where the substrate is entirely iron or entirely scale. Thus all scale should be removed by flame-cleaning, pickling or weathering, in addition to brushing off all powdery rust. Where thorough cleaning is impossible, a finishing paint should be applied. Colored

plates illustrate the atmospheric exposure tests and theoretical explanations are put forward for the phenomena observed.—ZDA. 14583

5.4.5, 1.6

Epoxy Resins: Their Application and Technology. HARRY LEE AND KRIS NEVILLE. Book, 1957, 305 pp. McGraw-Hill Book Company, Inc., 330 West 42nd St., New York 36, N. Y.

A comprehensive review of information on the epoxies. Extensive tabulated and diagrammed data are given on synthesis and characteristics; curing; amines, amides, organic acids, anhydrides as curing agents; diluents and fillers, plasticizers and flexibilizers, casting and potting, adhesives, laminates, coating, handling methods and safety precautions. An alphabetical chemical index is included. 14685

5.4.5, 2.2.7, 1.7.1

Report of Work of Commission on Marine Corrosion of A.B.E.M. (Belgium Society for Study, Testing and Use of Materials.) (In French.) J. DEPIREUX. *Ind. Chim. Belge,* **22,** 379-392 (1957) April.

Specimens of steel were immersed for 16 months in Port of Ostend prior to tests designed to show: 1) influence of surface conditions on behavior of a typical paint applied with or without wash-primer; 2) influence of time elapsing between application of wash-primer and of paint; 3) behavior of different wash-primer for a given prepared surface and a given paint.—MR. 14646

5.4.5

Re-evaluation of the Function of Pigments in Paints. A. C. ELM. *Official Digest, Federation Paint and Varnish Production Clubs,* **29,** No. 387, 351-385 (1957) April.

The author considers, in the light of modern developments, existing theories on subjects such as hiding power and color, yellowing of interior finishes, water resistance and washability, seeding, chalking and metallic paints. The advantages of zinc oxide are explained in preventing the yellowing of some paints, in retarding the breakdown of the film by ultra-violet light and in giving the film greater scrub-resistance. The way in which zinc dust paints protect steel is briefly described. The discussion following the paper includes short sections on primers containing zinc oxide, cathodic protection and zinc oxide in exterior latex paints.—ZDA. 14651

5.4.5

How to Make Painting Pay. G. H. WESCOTT AND P. T. WHITE. E. I. du Pont. *World Oil,* **145,** No. 1, 151-152, 157 (1957) July.

A systematic course of action designed to retard or eliminate corrosion damage through the judicious application of paint coatings is given. Fundamental principles of good painting practices are discussed as to good engineering design, proper surface preparation, choice of correct materials, controlled application and adequate film thickness. Use of plastic paints in storage tanks and offshore drilling equipment is discussed. Photos.—INCO. 14817

5.4.5

Technology of Highly Pigmented Zinc Dust Paints. K. ULBRICH. *Farbe u. Lack,* **63,** No. 9, 435-443 (1957).

Zinc-rich paints are pigmented on a weight basis up to a 94:6 ratio; on a volume basis, however, this pigmentation is only 1.6:1. It appears that the corrosion products of the zinc act as inhibitors for iron corrosion. Replacement of a portion of the zinc metal by zinc oxide, however, may reduce the degree of protection.—RPI. 14798

5.4.5, 2.2.2

Weathering Characteristics of Zinc Oxide Pigments. J. R. RISCHBIETH. *J. Oil Colour Chemists' Assoc.,* **40,** No. 3, 212-220 (1957) March.

42 commercially produced samples of zinc oxide were incorporated in linseed oil paints both alone and with other pigments, and were exposed out of doors in Australia. Two main types of oxide were distinguished; chalking (most indirect process oxides) which caused severe early chalking and premature failure by cracking and flaking, and chalk-resistant (most direct process and acicular oxides). Some oxides made by these processes were intermediate in character. Since the tests began some chalk-resistant indirect process oxides have been produced, and so the properties of a particular oxide cannot be predicted from its method of manufacture. Chalking developed sooner when exposures began in late spring than in late autumn. Daily spraying with water accelerated

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125a

early chalking but did not affect other types of failure.—ZDA. 14801

5.4.5

Theoretical and Electrochemical Basis of the Use of Zinc in Paint Systems. J. D'Ans and H. J. Schuster. *Farbe u. Lack,* **63,** No. 9, 430-434 (1957).

The use of zinc-rich paints was discussed. Protection of iron is not thought to be due to simple electrochemical action, as the area of contact between the metallic zinc and the iron is very small, and rapidly diminishes. Mechanisms involving the formation and diffusion of basic zinc salts are postulated. —ZDA. 14610

5.4.5

Aluminum Paints: Considerations Affecting Their Formulation. J. Breidenfeld. *Paint, Oil, Colour J.,* **131,** No. 3046, 481-482 (1957).

Properties required of aluminum powders suitable for use as pigments in aluminum paints, as well as characteristics essential in binders, solvents, driers and surface active agents in such paints are summarized. In addition, a survey is given of the different types of aluminum paints available and of their applications. These types include bronzing liquids, bitumen paints, heat-resistant paints for use on radiators or stoves, anticorrosive coatings, aluminum paints for use in gas works, rubber factories or wherever sulfur compounds are encountered, aluminum/chlorinated rubber paints, wood primers or top coats, or sprayable automobile coatings made from nitrocellulose lacquer and aluminum powder.—ALL. 14713

5.4.5

Usefulness of the Nitroparaffins and Other Derivatives in the Protective Coatings Industry. J. S. Long and Earl R. Gerhard. *Official Digest, Federation Paint and Varnish Production Clubs,* **29,** 542-559 (1957) June.

Preparation and reactions of epoxy resins; use of nitroparaffins in solvent mixtures for epoxies. Solvent and film properties of epoxy solutions; drying rates.—BTR. 14724

5.4.8, 5.4.2, 7.4.4

Surface Finishes for Heating Appliances: A Comparison Between Vitreous Enamel and Epoxide Paints. N. S. C. Millar. *J. Oil, Colour Chemists' Assoc.,* **40,** No. 6, 478-487 (1957).

The properties of epoxide/urea/formaldehyde systems and vitreous enamel systems were compared with reference to their requirements when applied to domestic heating appliances. The results indicated that the disadvantages of vitreous enamel as a surface finish for domestic heating appliances was its relatively poor chip-resistance when compared with epoxide finishes, whereas the epoxide systems were deficient in abrasion and heat resistance.—RPI. 14715

5.5 Oil and Grease Coatings

5.5.1, 5.6.1, 5.9.2

Temporary Rust Preventives. E. S. Lower and S. C. Cressey. *Machinery* (London), **90,** No. 2312, 537-540 (1957) March 8.

Classifies rust preventives according to types of films which they form. Discusses pre-treatment of surfaces and methods of application for oily film type and soft film and hard film solvent deposited type, including injection and hot dipping. Wrapping of treated parts and removal of rust preventives are covered. —BL. 13822

5.6 Packaging

5.6.3, 5.8.4, 4.4.7

Effect of Peroxide upon the Rust-Preventing Properties of Oils. S. Sato and Y. Kato. *J. Chem. Soc. Japan,* Ind. Chem. Section, **60,** No. 5, 556-560 (1957) May.

Turbine oil containing dissolved benzoyl peroxide or methyl oleates of various peroxide values prevents corrosion of mild steel in a proper peroxide-value range. Methyl oleate and soybean-oil purified by alkali showed other effective peroxide-value ranges; but when oxidized, they showed same effective range as benzoyl peroxide. Benzoyle peroxide, lauloyl peroxide, and di-t-butylperoxide have rust-preventive effect at some concentrations; however, their effective ranges are not always the same. Effective range was influenced by the condition of measuring the peroxide-value. Proper amounts of benzoyl peroxide showed synergistic effect with some polar organic corrosion-inhibitors by the method of static water drop test.—JSPS. 14417

5.8 Inhibitors and Passivators

5.8.2, 4.6.4, 2.2.7

Some Experiences with Sodium Silicate as a Corrosion Inhibitor in Industrial Cooling Waters. J. W. Wood, J. S. Beecher and P. S. Laurence. *Corrosion,* **13,** No. 11, 719t-724t (1957) Nov.

The use of sodium silicate as a corrosion control agent for open-recirculating cooling water systems is discussed. Emphasis is placed on the results of tests made with low-carbon steel coupons in eight operating plants. The normal development of silica films, effect of prior corrosion and the influence of pH, water temperature and magnesium hardness are discussed. Long-term test data indicated that crystalloidal silica is highly effective in stopping corrosion of mild steel by a wide variety of industrial cooling waters. Thirty to forty ppm of total crystalloidal silica provided adequate protection in waters containing upwards of 500 ppm of chlorides and sulfates. Magnesium hardness in concentrations above 250 ppm as calcium carbonate was found to greatly reduce the inhibitive action. 14401

5.8.2, 4.4.6, 8.4.3

Spray Injection of Liquids into High Pressure Gas Lines. F. E. Blount and J. W. Anthony. *Corrosion,* **13,** No. 12, 127-128 (1957) Dec.

A method of adding inhibitors as spray to high pressure gas lines is described. The method uses pressure differential created by an orifice plate upstream of a spray nozzle in a device which has no moving parts, gives satisfactory dispersal of inhibitor through a 26-mile line and through a gas lift system, and requires very little maintenance other than refilling tanks with inhibitor. 14502

5.8.3

Corrosion and Adsorption Studies Using Sulfonate Inhibitors. A. H. Roebuck, P. L. Gant, O. L. Riggs and J. D. Sudbury. *Corrosion,* **13,** No. 11, 733t-738t (1957) Nov.

The existing literature pertaining to the use of sulfonates as corrosion inhibitors is reviewed briefly. An account is given of radiometric adsorption and desorption studies made of sodium and amine salts of sulfonic acids. Corrosion inhibitor studies also were made of these salts in hydrogen sulfide and carbon monoxide environments; some of the variables encountered include the effect of: 1) concentration, 2) solubility, 3) molecular weight, and 4) extent of neutralization of sulfonic acid. A simplified explanation of the mechanism of sulfonate inhibitors also is given. 14434

5.8.3, 3.8.4

Adsorption of Surface-Active Substances on an Iron Electrode in Alkaline Solution. V. V. Losev and B. N. Kabanov. *Bull. Acad. Sci. U.S.S.R. (Izvest. Akad. Nauk S.S.S.R.),* Chemical Sciences Division, No. 4, 414-420 (1957) April.

Tetrabutylammonium, naphthylsulfonate, and caproate ions, and octyl alcohol do not lower capacitance of iron electrode and have little effect on hydrogen overvoltage. Tannin, alizarin, arsenous oxide, and phenol lower capacitance and increase overvoltage for potentials more negative than stationary potential, and have no effect on capacitance for potentials more positive than stationary potential. Results attributed to surface interactions, or lack of same. 6 figures, 8 references.—ATS. (Translation available: Associated Technical Services, P. O. Box 271, East Orange, New Jersey.) 14319

5.8.4

Sodium Polyphosphates and Their Use as Corrosion Inhibitors. (In Italian.) A. Indelli. *Metallurgia Italiana,* **49,** 333-336 (1957) May.

Physical properties and characteristics of sodium phosphates; description of their operation to prevent corrosion. Attempt at logical and coherent interpretation of their inhibiting action can be made on basis of different possible types of cathodic corrosion reaction and of surface activity characteristics of the compounds derived from these salts. 33 references.—MR. 14680

5.8.4, 4.3.2, 4.3.3

Study of the Inhibitor Properties of Some Commercial Additives. I. E. Titova. *J. Applied Chem., USSR (Zhur. Priklad. Khim.),* 30, No. 4, 576-581 (1957).

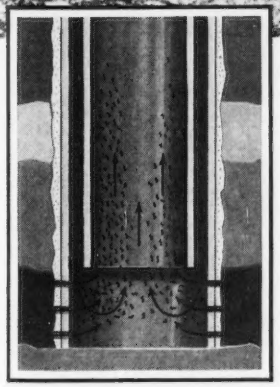
Five additives are tested as corrosion inhibitors for iron in hydrochloric acid and sulfuric acid and for aluminum in hydrochloric acid and alkali solutions. 3 tables, 5 figures, 8 references.—ATS. (Translation available: Associated Technical Services, P. O. Box 271, East Orange, New Jersey.) 14412

5.9 Surface Treatment

5.9.4, 3.5.8

Fatigue Durability of Carburized Steel. Papers before Am. Soc. Metals, 38th Nat'l. Metal Congress & Exposition, Cleveland, Oct. 8-12, 1956. Monograph, 1957, 123 pp. Available from American Society for Metals, 7301 Euclid Ave., Cleveland 3, Ohio.

Papers include: "Introduction," J. B. Bidwell (pp. 1-10); "Effect of Surface Condition on the Fatigue Resistance of Hardened Steel," G. H. Robinson (pp. 11-46); "Residual Stresses in Carburized Steels," W. S. Coleman and M. Simpson (pp. 47-67); "Fatigue Durability of Carburized Steels," J. G. Roberts and



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R. K. Mattson (pp. 68-105); "Summary," R. F. Thompson (pp. 106-115). —INCO. 14708

5.9.4

The Pretreatment of Metal Surfaces. M. Lewis. *Metal Finishing J.*, **3,** No. 25, 29-36 (1957) Jan.

In a paper presented to the North-West Branch of the Sheet and Strip Metal Users' Technical Association, the author discusses some of the proprietary processes used in the pretreatment of metal surfaces including many variations on the Parkerizing and the Bonderizing processes. The factors governing their use are enumerated.—ZDA. 14705

5.9.4, 5.9.2

Electrochemical Methods for Decorative Processing of the Surface of Aluminum Articles. P. V. Shchigolev. *J. Applied Chem., U.S.S.R. (Zhur. Priklad. Khim.)*, **30,** No. 6, 882-887 (1957).

Optimum conditions are given for electrolytic and chemical polishing. Anodizing procedure in sulfuric acid yielding transparent oxide films only slightly affecting the shine of the aluminum is recommended, and dye bath formulations for coloring aluminum gold and other colors are presented. 25 references. —ATS. (Translation available from Associated Technical Services, P. O. Box 271, East Orange, New Jersey.) 14759

5.9.4, 2.3.6

Investigation of the Secondary Structure of Anodic Surface Layers of Aluminum by Dye Adsorption. Pt. II. Kinetics of Dyeing. Th. Skulikidis, Ch. Papathanasiu and J. Marangosis. *Kolloid-Z.*, 150, 54-60 (1957); *Chem. Absts.*, **51,** No. 14, 10207 (1957) July 25.

The amount of dye adsorbed, x, by either one of the two aluminum oxide layers in time t is given by the equation, $x^2 = kt$; this indicates a chemical reaction. The energy of the activation is 21.5 kcal./mole, corresponding to control of rate by an interchange of places between dye and aluminum oxide, rather than by diffusion. In the first of x_1 layer, the rate constant k is proportional to the amount of electrical charge that has been passed, whereas for the second or x_2 layer it is independent of the amount of charge.—ALL. 14785

5.9.4

Anodic Film Protection of Aluminum and Aluminum Alloys. (In French.) W. Wiederholt. *Rev. Aluminium*, **34,** No. 245, 721-733 (1957) July-Aug.

Necessity for control of thickness and density of oxide coatings; measurement of coating thickness by microscope, chemical means and by the use of the isometer; colorimetric determination; permeability and efficiency of the various sealing processes; corrosion tests enabling accurate quality control of oxide coatings insuring efficient protection in normal atmospheres. 9 references. —MR. 14812

5.9.4

Formation and Growth of Protective Surface Layers on Aluminium. (In German.) Hans Ginsberg. *Z. Metallkunde*, **48,** No. 6, 357-360 (1957) June.

The processes accompanying the formation of protective layers on aluminum, and the theories advanced therefor are being surveyed. Current vs. voltage curves were measured during the formation of anodic films in slightly dissolving electrolytes, subsequent to the application of various surface treatments. The effect of irradiation before and after sealing of the layer is reported, and the results of microchemical investigations of the oxide coatings are discussed.—ALL. 14657

5.9.4

Effect of Cations Accumulating in the Electrolyte on the Process of Anodic Oxidation of Aluminum and Its Alloys. K. M. Filimonovich. *Ukrainian Chemical Journal (Ukrain. Khim. Zhur.)*, **23,** 97-102 (1957); *Chem. Absts.*, **51,** No. 14, 10273-10274 (1957) July 25.

The concentration of sulfuric acid should not drop more than 10-20 percent or the concentrations of aluminum and Cu^{++} climb above 17 g./l. and 0.0125 percent, respectively, in the electrolyte if durable coatings of good color are to be obtained. Zinc, nitrogen, iron, and magnesium ions which collect in the electrolyte have little effect on the coating.—ALL. 14652

5.9.4

Wear Protection of Mild Steel by Phosphating. J. W. Midgley. *J. Iron Steel Inst.*, **185,** 215-224 (1957) Feb.

A microscopic study of the change in the nature of mild-steel surfaces phosphated in an accelerated iron phosphate, or an accelerated iron-manganese phosphate bath, and of the changes during subsequent wear tests.—BTR. 13800

5.9.4, 6.3.20, 3.5.9

Dissolution of the Oxide Film on Zirconium. R. D. Misch. *Acta Metallurgica*, **5,** 179-180 (1957) March.

The rate of dissolution of the oxide film on zirconium when heated in vacuum was measured by comparing colors of anodic films before and after heating. Color changes were uniform and could be estimated to 90Å; a uniform reduction at the metal:oxide interface is indicated. A graph shows that the rate of film dissolution varies linearly with temperature over the range from 425 to 625 C.—MR. 13798

5.9.4, 6.2.3

Chemical Surface Preparation of Structural Steel After Erection. Christopher D. Coppard, John H. Lawrence, F. S. Bricknell and Henry W. Adams. *Corrosion*, **13,** No. 11, 141-142 (1957) Nov.

A method of removing millscale and preparing for coating structural steel by the application of chemicals after erection is described. Production of a phosphate coating by application of chemicals to chemically cleaned steel after erection is possible with materials developed in England and used extensively there. Some economic data indicate the cost of surface preparation by the chemical method has some advantages over sandblasting. Extracted from a paper "The Chemical Surface Preparation of Structural Steel" presented at a meeting of Northeast Region, National Association of Corrosion Engineers, Philadelphia, Pennsylvania, October 15-17, 1956. 14418

5.9.4, 6.3.15

Investigations Concerning the Anodic Oxidation of Titanium. (In German.) H. Bohm. *Metalloberflache*, **11,** No. 6, 197-200 (1957) June.

The experiments reported were car-

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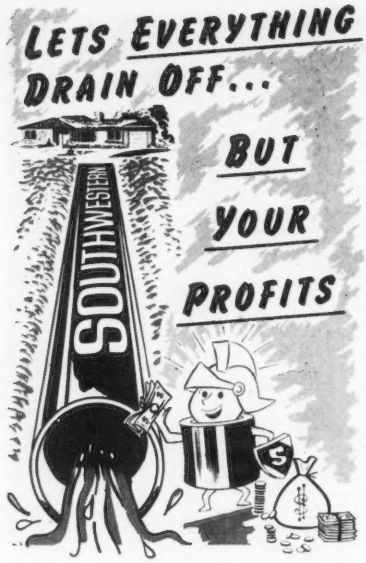

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ried out in electrolytes containing 1/10 N caustic potash, 1/10 N solution of sodium borate, and 1/10 N sulfuric and chromic acid in various concentrations. Pure and alloyed titanium sheet, titanium-7 percent manganese, titanium-6 percent aluminum-4 percent vanadium, titanium-4 percent aluminum-4 percent vanadium, titanium-5 percent chromium-13 percent aluminum were used as samples. It was observed that the current density vs. time curves exhibit a typically anodic character, that is, a substantial drop in current density takes place during the initial 5 minutes of testing. This behavior is believed to be the same in any electrolyte which does not contain halide ions; there is, however, a quantitative difference, according to polarity, in the passage of current. If, on the other hand, the electrolyte contains halide ions, chlorine or bromine, for example, local attack occurs and the rate of corrosion may be very high. The evolution of current/time curves in the case of an instantaneous voltage drop, is analyzed. Several graphs showing the differential behavior of titanium and aluminum are presented. It is said that the corrosion-resistance of titanium to sulfuric acid was markedly improved by anodizing, but its susceptibility to attack by hydrofluoric acid has remained unchanged. Since titanium is violently attacked by halides not containing water and even a 5 percent solution of bromine in methyl-alcohol, after 2 hours exposure, causes severe pitting, the performance of anodized sheet was tested in this medium. Anodized titanium was found to exhibit better resistance; the onset of corrosive attack did not manifest itself but after more than 30 hours of exposure. It is noted that, starting at the edges and progressing underneath the oxide film, the corrosion ultimately completely destroys the entire metal stock and only the anodic films remain preserved in the solution. —ALL. 14347

5.9.4, 3.2.2

Embrittlement of Phosphated Steel. H. P. Weinberg and T. J. Capello. *Metal Progress,* **71,** No. 4, 78-81 (1957) April.

Investigation of conditions under which phosphate coatings induce embrittlement and treatments required to prevent embrittlement when it occurs. Effect of phosphate coating on high-strength steel was evaluated by sustained static load test on a notched specimen. Material used was ⅜ in. 4340 steel rod (0.40 carbon, 0.027 phosphorus, 0.015 sulfur, 0.68 manganese, 0.23 silicon, 1.80 nickel, 0.83 chromium and 0.25 molybdenum). Several test specimens from different hardness groups were aged at 220 F. for 1 hr. High-strength steel, hardened and then tempered at 875 F. could be phosphated without embrittlement, even without taking precaution of subsequent baking. Over-all conclusion drawn is that embrittling effect of phosphate coatings can be prevented by either aging for 24 hr. at room temperature or 1 hr. at 220 F. Tables, photo.—INCO. 14351

5.9.4

Temperature Rise During Formation of Anodic Oxide Films. Lawrence Young. *Trans. Faraday Soc.,* **53,** No. 2, 229-233 (1957).

Cf. *(ibid.,)* **50,** 153 (1954). Young calculates that during the formation of an anodic oxide-film on electrodes immersed in an unstirred solution the temperature rise for 50 V. is 1.2 C. at 1 m.amp./cm.^{2} and $\propto$ current density. These calculations were verified for niobium and tantalum by measuring the rate of rise of potential at constant current density, with and without stirring.—MA. 14370

5.9.4

Some Properties of Oxide Layers Produced on Aluminium by Electrolytic Oxidation. W. Ch. van Geel and B. J. J. Schelen. *Philips Research Repts.* (Netherlands), **12,** No. 3, 240-248 (1957) June.

A description is given of measurements of the thickness (d), dielectric constant (ε) and density (ρ) of oxide layers produced on aluminum by electrolytic oxidation. The X-ray investigation of the structure of these layers was also undertaken. Two different values were found for the thickness of the layer, viz. d = 13.7 Å/volt and d = 12.7 Å/volt. The former value was found after chemical cleaning, the latter without any prior removal of the oxide layer formed by reaction with the air. The cleaning probably causes an increase of about 7 percent in the surface area. If this is correct, then d = 12.7 Å/volt is the more acceptable value. For ρ we found the value 3.1 g./cm.^{3}, for the value 8.7. When it is formed at room temperature, the oxide is completely amorphous, except when a layer of boehmite has been produced on the aluminum by boiling it in water. In the later case γ'-Al_2O_3 is also formed. Oxidation at 100 C gives some γ'-Al_2O_3 as well as amorphous Al_2O_3. (auth.)—ALL. 14373

5.9.4, 5.3.2

Anti-Corrosion Treatment of Galvanized Articles. (In Russian.) N. A. Solov'ev and A. A. Gorbenko. *Metallovedenie i Obrabotka Metallov,* No. 2, 54-58 (1957) Feb.

Discussion of a process for increasing anti-corrosive property of galvanized articles by treating with a solution of chromium anhydride, sulfuric acid, and hydrochloric acid.—BTR. 14398

5.9.4

Effects of Various Polyvalent Metal Anion Additions to an Alkaline Magnesium Anodizing Bath. W. McNeil and R. Wick. *J. Electrochem. Soc.,* **104,** No. 6, 356-359 (1957) June.

Protective coatings on FS1 magnesium alloy can be obtained by anodizing in a bath prepared from potassium hydroxide, aluminum hydroxide, trisodium phosphate, and potassium fluoride. The addition of stannate, vanadate, manganate, chromate, or tungstate to this bath makes it possible to produce coatings which differ with respect to color and corrosion resistance. The corrosion resistance of all these coatings is greatly improved by a post treatment consisting of immersion in a bifluoride-dichromate solution followed by ageing in a hot, humid atmosphere. The addition of vanadate increases the corrosion resistance of the coating. All the coatings studied are hard enough to abrade Rockwell C63 steel.—ALL. 14323

5.9.4

Passivation of Iron by Chromate Solutions. D. M. Brasher, A. J. Kingsbury, A. D. Mercer and C. P. De. *Nature,* **180,** No. 4575, 27-29 (1957) July 6.

Investigation of amount of chromium in protective films formed on iron during immersion in potassium chromate solution. Graphs show that film growth in air and in chromate solution are both linear functions of log (time) differing only in their rate of constants. Rate of

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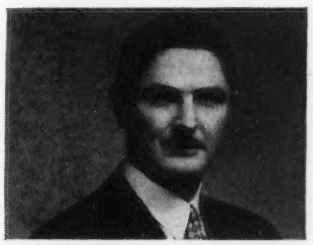

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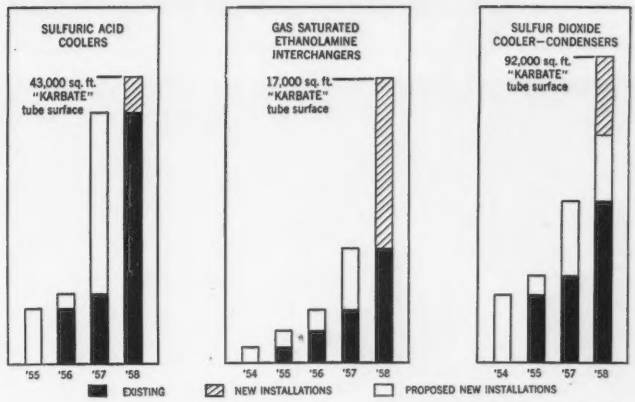

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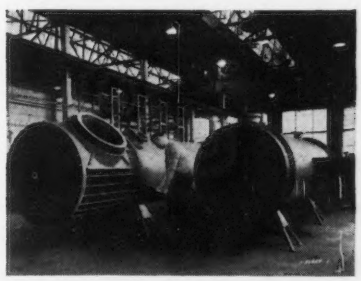

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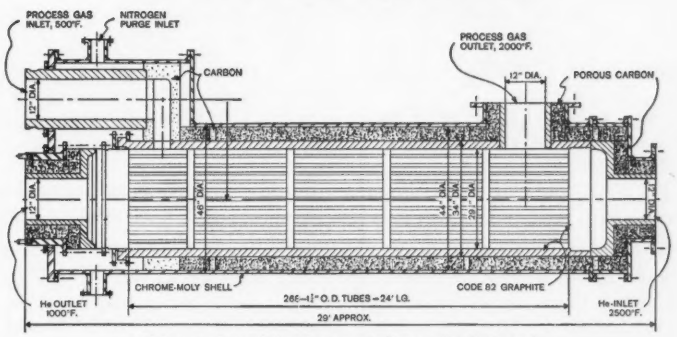

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Because operating temperatures range from 2000° to 2500° F., "National" Code 82 graphite is well suited for such applications. This low permeability material used for constructing the shell and tube heat exchanger shown provides high heat transfer rates, freedom from corrosion and metallic contamination, and resistance to thermal shock.

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uptake of chromium and hence presumably rate of oxidation by chromium ion, is considerably influenced by amount of oxygen in solution. Rate in a solution saturated with nitrogen is more than double that occurring in the same solution saturated with oxygen. It would appear that oxygen and chromate ions compete in oxidizing the iron surface. The picture of inhibition by chromate may be as follows. Immediately on immersion of the iron or steel in the chromate solution, an adsorbed layer containing chromium ions is formed. This is followed by "logarithmic" growth of an oxide film, with an adsorbed film always present. It is not possible at this stage to distinguish between relative contributions towards inhibition of the adsorbed layer and of chromium-containing oxide film, since both are always present, though it is known that the longer the period of immersion, that is, the thicker the oxide, the greater the degree of protection.—INCO. 14591

6. MATERIALS OF CONSTRUCTION

6.2 Ferrous Metals and Alloys

6.2.2

Thermal Balance Used for Oxidation Tests on Cast Irons Containing Aluminum and Chromium. N. COLLARI AND E. HUGONY. *Metallurgia Italiana,* **49,** 341-348 (1957) May.

Test pieces were heated in air at 800 C. for as long as 3 hours. In normal or low-alloy cast irons, white aluminum-chromium cast iron, and a heat resistant chromium steel which was tested for purposes of comparison, an increase in weight was noted. In gray (graphite) cast irons containing aluminum, a decrease in weight was noted, due to surface oxidation of carbon. Aluminum, under given test conditions, provided a higher resistance to heat than chromium. 9 references.—MR. 14616

6.2.2

Corrosion of Puddled Iron. (In Italian.) NELLO COLLARI. *Calore,* **28,** 147-153 (1957) April.

Structure of puddle iron; probability and speed of corrosion; possibilities of using new knowledge to produce a less expensive product than puddled iron, but one that will retain its valuable characteristics. 7 references.—MR. 14618

6.2.2, 3.7.3

Investigation on Acid-Resistant High-Silicon Iron. Pt. 3. Effects of Cooling Rate and Annealing on Mechanical Properties and Corrosion Resistance. (In English.) HIROSHI SAWAMURA, OSAMU TAJIMA AND KYOICHI AKAMATSU. *Memoirs, Faculty of Engineering, Kyoto Univ.,* **19,** No. 1, 77-91 (1957) April.

Variations in cooling rate bring about great changes in graphite structure and influence mechanical properties although not corrosion resistance. The annealing of castings is important only with respect to the relief of internal casting stress. 6 references.—MR. 14770

6.2.2, 4.3.2

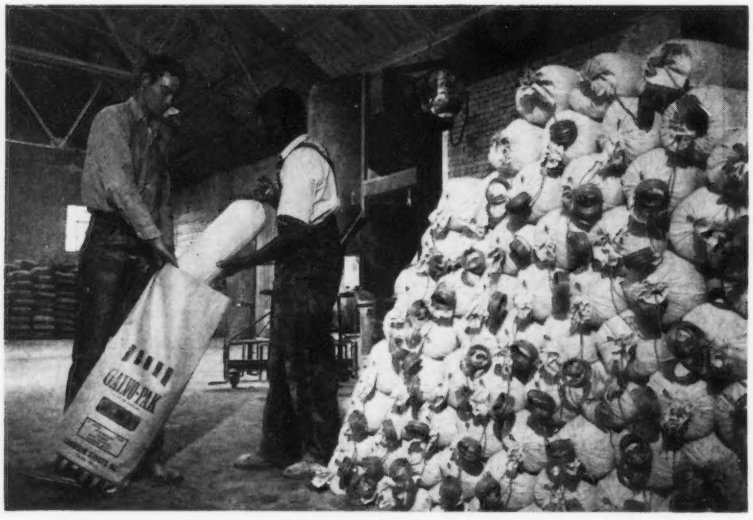
Investigation on Acid-Resistant High-Silicon Iron. Pt. IV. Corrosion Resistance to Sulphuric Acid. (In English.) HIROSHI SAWAMURA, OSAMU TAJIMA AND KYOICHI AKAMATSU. *Memoirs, Faculty of Engineering, Kyoto Univ.,* **19,** No. 1, 92-101 (1957) April.

Corrosion tests were carried out on acid-resistant high-silicon iron in sulfuric acid with various concentrations and temperatures. The effects of the acid concentration, temperature and duration of test are discussed. The appearance of the surface of the specimen is also examined. 4 references.—MR. 14772

6.2.2, 8.8.1

Large Iron Castings in One Branch of the Chemical Industry. G. A. J. BEGG. Paper before Brit. Cast Iron Res. Assoc. Conf. on Engineering Properties and Uses of Iron Castings, London, November, 1956. *J. Research and Development, Brit. Cast Iron Research Association,* **6,** No. 11, 608-623; disc., 623-628 (1957) April.

Author emphasizes difficulty encountered in obtaining castings for applications in Alkali Div. of I.C.I., free from defects due to sand inclusions, porosity, unfused chaplets, displaced cores, etc.; and cracking due to high internal stresses. Requirements for castings to be used in chemical industry are outlined, and tonnage used is indicated. Details are given of failure, and subsequent redesign, of specific castings in alkali service. These include conical casting, cylinder and tube plate for evaporator, caustic pot, and finned heat recovery pot, all made from 1 nickel cast iron. Effects of carbon, nickel, sulfur and phosphorus on soundness, corrosion resistance and general performance are discussed. In discussion, S. H. Smith mentioned that replacement of grey iron tube-plate by nodular iron tube-plate was not possible due to susceptibiilty of nodular iron to stress-corrosion cracking.—INCO. 14701



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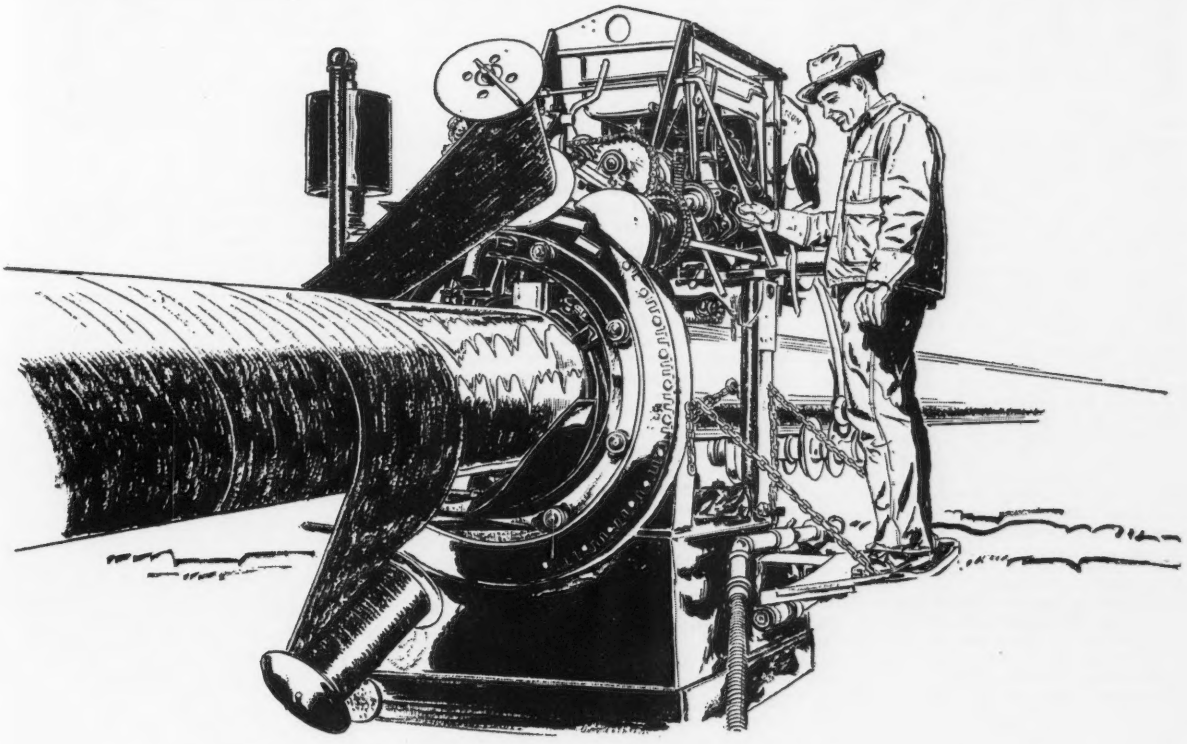

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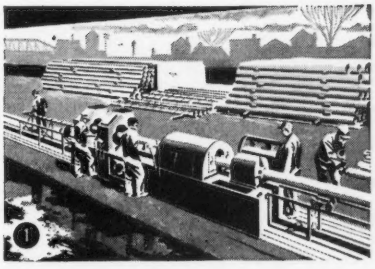

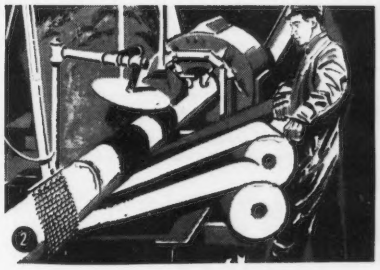

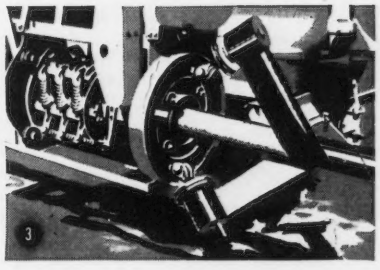

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6.2.2

Development of Cast Iron-Base Alloys of Austenitic Type for High Heat-Resistance and Scale-Resistance. F. EBERLE, J. H. HOKE AND W. E. LEYDA. Babcock and Wilcox Co. Research Center. U. S. Wright Air Development Center, January, 1957, 99 pp. Available from Office of Technical Services, U. S. Dept. of Commerce, Washington 25, D. C. (Order PB 121950).

This project was concerned with the development of iron-base alloys to substitute for the cobalt-base alloy H.S. 21. The most promising alloys contained a minimum iron content of 45 percent, minimum carbon content of 0.50 percent, chromium not less than 20 percent, and between 27 and 32 percent nickel, part of which could be replaced by cobalt. Those alloys, strengthened with 5-percent additions of niobium, tantalum, molybdenum and tungsten, developed a creep-rupture strength at 1600 to 1800 F approaching that of H.S. 21. They were equal to H.S. 21 in oxidation resistance at 2000 F, but inferior in short-time cold and hot tensile strength, cold ductility and resistance to thermal shock and thermal fatigue. The possibility of improving the thermal properties by lowering carbon content and compensating for the resulting decrease in rupture strength with modifications in composition seemed plausible, but was not explored.—OTS. 14273

6.2.4, 3.7.2

An Investigation of the Fatigue Characteristics of Leaded Alloy Steels. G. W. BROCK AND G. M. SINCLAIR. University of Illinois. U. S. Bureau of Ordnance, U. S. Navy, March, 1957, 57 pp. Available from Office of Technical Services, U. S. Dept. of Commerce, Washington 25, D. C. (Order PB 121834).

There is no significant difference between the fatigue strengths of leaded and non-leaded steel having ultimate strengths below 130,000 psi, this report concludes. Above that figure, however, fatigue strength of leaded steel declines. The study concerned the influence of small amounts of lead on tensile and fatigue properties of SAE 1018, 1045, 8620, and 4340 alloys. Although the effects of lead on tensile properties of alloy steels had been established as insignificant, litle work had been done on effects on fatigue strength. Tensile tests confirmed that lead additions of about 0.2 percent have no significant effect on measured mechanical properties. Possible drops in mean fatigue strength of leaded steels were shown to be about 8 percent at 170,000 psi and 16 percent at 275,000 psi. In the presence of a notch, practically no difference existed between the fatigue strengths of leaded and non-leaded steels in the ultimate tensile strength range of 70,000-170,000 psi, and very little difference at 275,000 psi.—OTS. 14551

6.2.5, 3.7.3

Alloys for Brazing Thin Sections of Stainless Steel. A. S. MCDONALD. Paper before Am. Welding Soc., Nat'l. Spr. Mtg., Philadelphia, April 8-12, 1957. *Welding J.*, **36,** No. 3, 131s-140s (1957) March.

Following brazing alloys: 72 silver-28 copper, 72 silver-28 copper-0.5 lithium, 85 silver-15 manganese, 85 silver-15 manganese-0.5 lithium and 68 manganese-32 nickel are discussed with respect to brazing stainless steel in thin sections. Results of wetting tests on specimens of 0.062-in. gage Type 304, 321 and 17-7 PH in hydrogen atmosphere at various dew points and temperatures are presented which demonstrate effects of lithium additions in aiding wetting of base metal and increasing fluidity of filler metal. Data are given on solution and penetration characteristics of alloys in comparison with typical nickel-chromium-silicon-boron alloy and copper. Although 68 manganese-32 nickel will dissolve stainless steel base metal, it is by no means as severe as nickel-chromium-silicon-boron. Oxidation resistance data are shown in graphs. Photomicrographs.—INCO. 13809

6.2.5

Production and Fabrication of New AISI Types 201 and 202. G. W. HINKLE. Paper before Am. Soc. Testing Materials, 59th Ann. Mtg., Atlantic City, June 1956. *ASTM Bull.*, No. 220, 47-50 (1957) Feb.

Summarizes information on melting practice, hot and cold rolling in blooming and strip mills, forging, annealing, pickling, brake and roll forming, deep drawing, polishing and welding of AISI Types 201 and 202. Table lists effects of lower annealing temperature (1800-1950 F) on mechanical properties. Charts show cold rolling practice, oxidation characteristics, and hardness and gage surveys of deep-drawn parts. Stress corrosion cracking tests in boiling 10 molar lithium chloride show no difference in cracking of comparative samples of drawn 201, 202 and 302.—INCO. 14689

6.2.5

Carbide Precipitation in Type 304 with Extra Low Carbon Content. (In Dutch.) A. OOLBEKKINK. *Metalen*, **12,** 244-247 (1957) July 15.

Investigation of 18/8-type steel with carbon content of 0.03 percent, which was thought sufficiently low to prevent carbide precipitation. Corrosion tests, after steel had been held at 650 C for one hour and furnace-cooled, showed that sufficient precipitation had taken place to impair corrosion-resistance. During welding, the steel is at critical temperature for too short a time for precipitation to take place, and has advantages over stabilized 18/8 types with higher carbon content.—INCO. 14739

6.3 Non-Ferrous Metals and Alloys—Heavy

6.3.5, 3.7.2

Studies of the Oxidation and Contamination Resistance of Binary Niobium Alloys. CHESTER T. SIMS, WILLIAM D. KLOPP AND ROBERT I. JAFFEE. Battelle Memorial Institute. U. S. Atomic Energy Comm. Pubn., BMI-1169, Feb. 19, 1957, 54 pp. Available from Office of Technical Services, Washington, D. C.

A study of the effects of binary alloying additions on the oxidation and contamination resistance of niobium has been conducted. The alloys contained up to 35 at. percent titanium, chromium, and zirconium, 25 at. percent vanadium, molybdenum, tantalum, and tungsten, and 5 at. percent berlylium, boron, cobalt, iron, manganese, nickel and silicon. The oxidation and contamination studies were conducted in air at 600, 800, and 1000 C. Four elements, titanium, vanadium, molybdenum and chromium, improved oxidation resistance. The concentrations for optimum oxidation resistance at 1000 C were 25 at. percent titanium, 10 at. percent vanadium, 5 at. percent molybdenum, and 25 at. percent chromium. Titanium was most effective in reducing the rate of oxidation; at 600 to 1000 C, the niobium-25 at. percent titanium alloy oxidized one-tenth to one-twentieth as rapidly as pure niobium. Contamination was investigated by hardness-penetration measurements on all oxidized alloys except those containing beryllium or boron. Zirconium and titanium markedly reduced the depth of oxygen contamination resulting from exposure to air. Diffusion coefficients for oxygen in the niobium binary alloys were calculated and related by activation-energy plots where possible.—NSA. 14365

6.3.8, 3.6.8, 3.8.4

Anodic Corrosion and Hydrogen and Oxygen Overvoltage on Lead and Lead Antimony Alloys. P. RUETSCHI AND B. D. CAHAN. *J. Electrochem. Soc.*, **104,** No. 7, 406-413 (1957) July.

Constant current techniques permit rapid evaluation of the anodic corrosion of lead and lead antimony alloys. The amount of lead dioxide formed during anodization can be evaluated by measuring the length of the potential plateau of the lead dioxide/lead sulfate couple produced during discharge. The rate of self-discharge and the degree of utilization of the lead dioxide must be taken into account in order to obtain correct corrosion figures. Methods for evaluating the self-discharge and degree of utilization of the lead dioxide are described.

X-ray diffraction patterns were taken of the anodized lead and lead-antimony alloy samples. Patterns of lead sulfate, lead, α-lead dioxide, and β-lead dioxide were observed, but there was no indication that lead oxide was formed on any sample. The principal anodization product was α-lead dioxide, a new crystalline modification of lead dioxide. Hydrogen and oxygen overvoltages were measured on various alloys of the lead-antimony system, using interrupter techniques. Overvoltage and anodic corrosion of single crystal faces of lead were also investigated. 14413

6.3.9

Protection of Molybdenum Against Oxidation at High Temperature. (In German.) KARL WASSMANN. *Ver. deut. Ing., Z.*, **99,** 423-425 (1957) April 1.

Problems of protection molybdenum surfaces against oxidation at elevated temperatures is discussed. No molybdenum alloy has been found that would correct the inability of molybdenum to form a protective oxide film. It is therefore necessary to resort to coatings which may be either inert themselves (like ceramics or certain metals) or oxidizable into an inert protective layer. Such coatings can be applied by spraying. The best experimental results have been obtained with chromium, chromium-nickel and aluminum-chromium-silicon, giving protection up to 1100 C, and with molybdenum sulfide for temperatures above 1300 C.—MR. 14364

6.3.14, 5.3.2, 3.2.2

The Corrosion of Tin and Tinned Copper in Dilute Neutral Solutions. S. C. BRITTON AND D. G. MICHAEL. *J. Applied Chem.*, **7,** No. 7, 349-356 (1957) July.

The occurrence of local corrosion of tin surfaces in dilute chloride solutions is not associated with surface conditions. Repeated removal of oxide from a tin surface at sufficiently frequent intervals prevents the development of local corrosion. The initiation of local corrosion is accelerated, and the number of points

of attack is increased by: crevices produced by some surface defects and by contact with another solid surface, lowering the pH of the solution below four, and contact with a more noble metal such as copper or nickel. Wiped coatings on copper are more susceptible to local corrosion than electrodeposited or hot-dipped coatings since the surface presented to the corroding solution is a mixture of tin and tin-copper compounds which form a galvanic couple. Alloying additions of zinc, phosphorus or indium which improve the resistance of tin to dry oxidation, do not prevent local corrosion by chloride solutions. The addition of chromate, benzoate, bicarbonate, silicate, nitrite, or phosphate to chloride solutions in adequate amounts make them non-corrosive to tin. The presence of bicarbonate in most supply waters probably restricts the number of occurrences of local corrosion. Local corrosion can be prevented by cathodic protection with aluminum anodes.—BTR. 14571

6.3.15

Utilization of Low-Grade Titanium Sponge Produced by the Kroll Process. Pt. II. The Oxidation of Titanium-Iron Alloys at Elevated Temperatures in Air. (In Japanese.) KAXUO HIRAYAMA, TORAO INAGAKI AND TAKESHI TAKEI. *Sci. Res. Inst. Repts., Tokyo,* **33,** 58-64 (1957) March.

The oxidation behavior of low-grade titanium containing up to 12 percent iron (byproduct of the Kroll process) was studied between 500 and 1000 C in air. In the vicinity of 500 C the oxidation of the alloys was slight but increased at temperatures above 600 C. With increasing temperature, the oxidation of the alloys obeyed a simple law. With increased time (up to 36 hr.), the process progressed approximately according to the parabolic law. The iron contents of the low-grade titanium did not affect the oxidation appreciably. It was observed that the penetration of oxygen at temperatures above 800 C was considerable. The structures of the resultant penetrated zone were investigated using microscopy, X-ray and electron diffraction. 6 references.—MR. 14691

6.3.15, 4.6.11

Corrosion Resistance of Titanium to Sea Water. J. B. COTTON AND B. P. DOWNING. *Trans. Inst. Marine Engrs.,* **69,** No. 8, 311-319 (1957) Aug.

Detailed information upon the behavior of titanium in sea water has been assembled to focus attention upon the advantages which might follow use of this metal or its alloys in certain marine engineering equipment. The basic physical properties of titanium and some of the more important alloys are summarized and reference is made to their good corrosion resistance. The protective nature of surface films present on massive forms of titanium is demonstrated by means of electrode potential measurements, and details of behavior in flowing sea water are given. Resistance to erosion in sea water carrying abrasive material is demonstrated and good performance in wet steam travelling at high velocity is noted. Attempts to produce corrosion at crevices are described and a detailed account is given of the behavior of galvanically coupled specimens, demonstrating that titanium does not suffer attack and indicating the likely degree of galvanic corrosion of the less noble metals. Experimental evidence is recorded to illustrate high corrosion fatigue strength and indicating excellent resistance to stress corrosion effects. Finally, the economic aspects of the use of titanium are discussed.—TIME. 14613

6.3.15

On the Corrosion Resistance of Titanium Alloys. (In Japanese.) S. YOSHIDA, S. OKAMOTO AND T. ARAKI. *J. Japan Inst. Metals,* **21,** No. 3, 183-186 (1957) March.

The corrosion rates of binary titanium alloys were determined in sulfuric, hydrochloric and nitric acids, aqua regia, acetic, formic and oxalic acids, ammonia water and sodium hydroxide, sodium chloride, ferric chloride, aluminum chloride solutions at ordinary and boiling temperatures. The added elements were aluminum, silver, tin, silicon, chromium, manganese, iron, cobalt, nickel, copper, tungsten and molybdenum. The alloys were arc-melted in argon atmosphere. They were hot and cold rolled to 1 mm thick plates and then cut into specimens for the corrosion test. Among the tested alloys, titanium-molybdenum alloys containing more than 20 percent molybdenum were shown to be highly resistant to hydrochloric and sulfuric acids which attack pure titanium severely. But the superior corrosion resistance of titanium in nitric acid is deteriorated by the addition of molybdenum. The comparatively poor corrosion resistance of titanium in formic and oxalic acids and aluminum chloride solution was shown to be much improved by the addition of appropriate elements.—JSPS. 14809

6.3.15, 3.8.3

Corrosive Properties and Passivation of Titanium and Its Alloys. (In German.) ULRICH ZWICKER. *Chem.-Ing.-Tech.,* **29,** 107-109 (1957) Feb.

It is known that mixtures of hydrochloric and nitric acid generate corrosion resistant films on the surface of titanium and its alloys. A closer study of this phenomenon was made by observing the corrosive behavior of pure titanium, of commercial titanium containing considerable iron, and of the ternary alloys titanium-chromium-aluminum and titanium-aluminum-vanadium in the presence of 20 percent hydrochloric acid alone or in mixtures with various amounts of nitric acid. In view of the differences in the composition of the materials examined, the differences observed are rather complicated, some alloys being less resistant than pure titanium while others are more resistant. In most cases the addition of 1.3 percent nitric acid to hydrochloric acid produced the strongest passivation effects.—MR. 14827

6.3.15, 3.7.2

Molybdenum as an Alloy Addition for Titanium. HAROLD MARGOLIN. New York Univ. *Metal Progress,* **71,** No. 2, 86-91 (1957) Feb.

A 7 percent aluminum, 3 percent molybdenum alloy has superior strength-weight properties at elevated temperatures. Molybdenum also has favorable influence on hardenability and oxidation resistance. It seems possible that, with its help, a useful age-hardenable alloy can be developed. (auth.)—NSA. 13786

6.3.17, 4.6.1, 3.5.11, 8.4.5

Aqueous Corrosion of Uranium and Uranium-6 w/o Zirconium Alloy (Work Performed: 1953-1954). W. E. RUTHER AND W. B. SEEFELDT. Argonne National Lab. U. S. Atomic Energy Comm. Pubn., ANL-5672, January 9, 1957, 15 pp. Available from Office of Technical Services, Washington, D. C.

The corrosion rates of uranium subjected to heat treatments of 600, 720, 800 and 1000 C asymptotically approached the lower corrosion rate of high purity uranium. Experiments in which hydrogen was deliberately added to heat-treated samples showed no correlation between corrosion rate and the hydrogen content. At a flow velocity of about 20 ft/sec of distilled water, uranium-zirconium alloy corroded at low, but increasing, rates at 60 and 90 C. The water was saturated with a nitrogen—4.7 mol percent oxygen mixture. The protective oxide film formed on initial immersion became less adherent and lost its interference colors after 30 days at 90 C. At 60 C this change of protective film occurred only at edges and corners. The increasing corrosion rate with time made it impossible to assign

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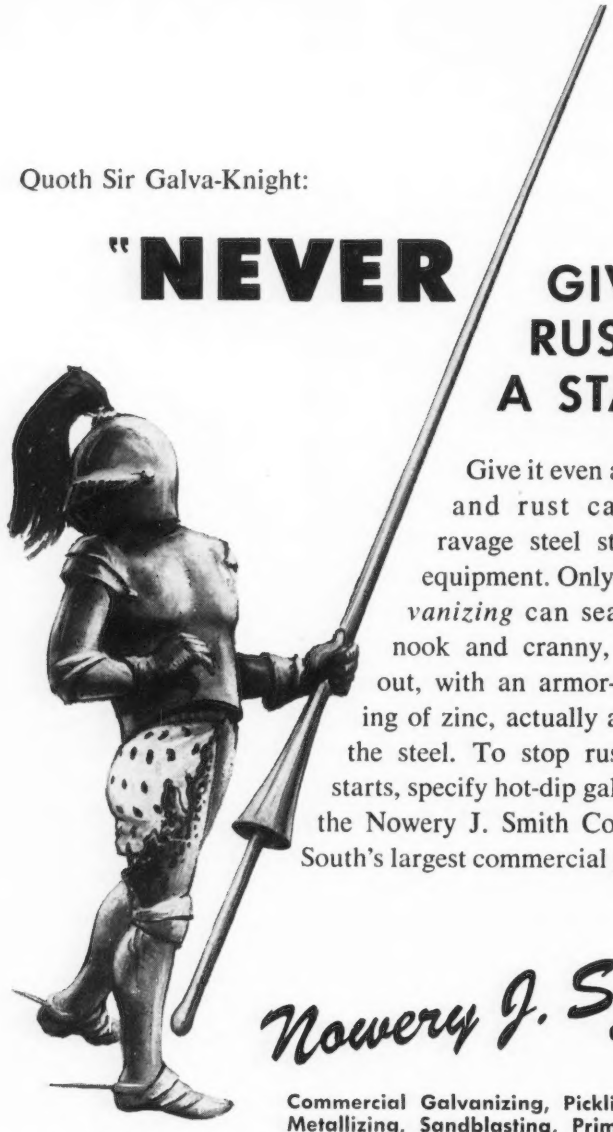
any single value for a corrosion rate. Little or no effect of the water flow rate was indicated by comparison of results with the previously reported behavior in static water. (auth.)—NSA. 14429

6.3.17

The High Temperature Aqueous Corrosion of Uranium Alloys Containing Minor Amounts of Niobium and Zirconium. J. E. Draley, S. Greenberg and W. E. Ruther. Argonne National Lab. U. S. Atomic Energy Commission Pubn., ANL-5530, April, 1957, 45 pp. Available from Office of Technical Services, Washington, D. C.

Alloys of uranium with niobium show good corrosion resistance in degassed, distilled water to about 315 C. The alloys must be quenched from the gamma phase in order to have high temperature corrosion resistance. The corrosion resistance is destroyed by over-aging at temperatures as low as 350 C. Of those tried, the alloy with best resistance to thermal aging is the uranium-5 percent zirconium-1.5 percent niobium alloy. At 290 C, optimum heat treatment can result in a rate of corrosion of about 6 mg/cm²/day. Certain moderate aging treatments, e.g., 400 C for two hours, result in improved corrosion resistance in the initial stages of corrosion. Alloys containing 3 percent niobium and small amounts of tin show promise. In addition to aging, the alloys are also sensitive to hydrogen content. Ultimate corrosion failure is believed due to absorption of corrosion product hydrogen. (auth.)—NSA. 14649



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6.3.18, 8.4.5

Selected Properties of Vanadium Alloys for Reactor Application. K. F. Smith and R. J. Van Thyne. Argonne National Lab. U. S. Atomic Energy Comm. Pubn., ANL-5661, May, 1957, 33 pp. Available from Office of Technical Services, Washington, D. C.

Selected vanadium-base alloys have been investigated as to tensile and creep strength, corrosion resistance, and thermal conductivity at elevated temperatures for the purpose of making a preliminary evaluation of suitability for use as fuel-element jacketing materials for sodium-cooled reactors. Results indicate preliminary feasibility of these alloys from all viewpoints under examination and suggest the desirabiilty of studying fabrication problems of alloys and improved reduction methods for vanadium metal. (auth.)—NSA. 14757

6.3.20

An Evaluation of Data on Zirconium-Uranium Alloys. Frank A. Rough. Battelle Memorial Institute. U. S. Atomic Energy Comm. Pubn., BMI 1030, August 19, 1955 (Declassified February 14, 1957), 112 pp. Available from Office of Technical Services, Washington, D. C.

A survey of the literature relative to zirconium-uranium alloys was made. The available data were analyzed in an attempt to present the most coherent and reliable picture of the behavior and nature of the zirconium-uranium alloys as a system. The constitutional diagram was reviewed, and an attempt was made to reconcile the divergent forms of this diagram found in the literature. The structure of the intermediate phase, epsilon, is discussed. The two modes of transformation of the beta (high temperature) phase are described; one mode resembles the martensite transformation found in steels; the other mode resembles in some respects the age-hardening-type transformation found in titanium alloys. Typical microstructures produced by transformation of beta, by cold working and annealing, and by duplex heat treatments are shown. An attempt was made to correlate structure with the manner in which it was produced and with the resultant mechanical properties. The available data on the hardness, tensile, and creep properties of zirconium-uranium alloys are tabulated and evaluated in the light of recent developments in the field of transformation kinetics. The physical properties of the alloys are presented in graphical form. The best available techniques for hot rolling, extruding, cold rolling, and swaging are detailed. The corrosion resistance of zirconium-uranium alloys in water at various temperatures is reviewed. The effect of ternary additions upon corrosion resistance is discussed with a view toward improving the alloys by this means. The effect of neutron irradiation upon metals is discussed, in general with respect to fuel alloys, and specifically with respect to zirconium-uranium alloys. (auth.)—NSA. 14836

6.3.20, 3.7.1, 3.2.3

The Diffusion of Oxygen in Zirconium and Its Relation to Oxidation and Corrosion. J. Paul Pemsler. Nuclear Metals Inc. U. S. Atomic Energy Comm. Pubn., NMI-1177, May 31, 1957, 49 pp. Available from Office of Technical Services, Washington, D. C.

The diffusion of oxygen in zirconium and dilute zirconium alloys was studied in the temperature range of 400 to 585 C

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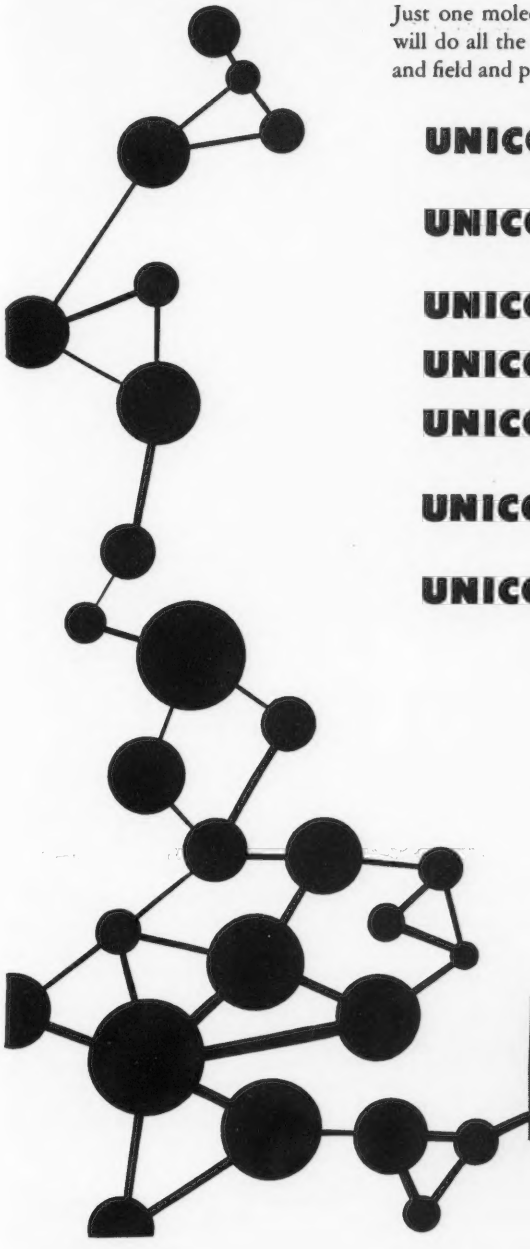

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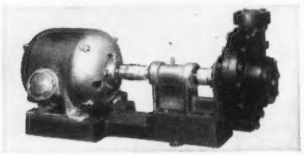

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by observing the rates of dissolution of anodically deposited interference oxide films. The diffusion coefficient of oxygen in zirconium depends on the grain orientation and varies by the factor of two among different orientations. Macroscopically observed average values obey the equation D, $cm^2/sec = 9.4 \exp [(-51{,}780 \pm 220)/RT]$, where the activation energy for the diffusion of oxygen in zirconium is 51.8 kcal/mole. No macroscopic differences were observed in the diffusion coefficients of the various dilute alloys. The effect of alloying additions and heat treatment on diffusion rates of individual grains is discussed. Oxidation and corrosion rates were observed to have an orientation dependence similar to that observed in the diffusion study. The mechanism of oxidation and corrosion is discussed in terms of diffusion of oxygen and adherence of oxide films. (auth.)—NSA. 14793

6.3.20

Studies on Corrosion of Metals with a Pulse-Polarizer. Part II. Corrosion of Zirconium. (In Japanese.) H. NODA AND T. MURAMATSU. *J. Metal Finishing Soc. Japan*, **8**, No. 1, 23-24 (1957) Jan.

In this research the corrosion properties of zirconium were examined, using zirconium-plate (1 cm × 1 cm) of 99.99 percent purity as anode and maintaining the temperature of the cell at 20 C, other conditions being the same as in the former research.

Results: In sulfuric acid although the amount of corrosion is small in the range of concentration 10-55 percent, corrosion proceeds at about 5 percent, 60 percent and more. In hydrochloric acid, the amount of corrosion is large, and independent of the concentration.

The amount of corrosion in nitric acid, phosphoric acid, acetic acid, ammonium hydroxide and potassium hydroxide was small.

In sodium chloride solution, the corrosion rate is similar to that in hydrochloric acid owing to the effect of chlorine ion.

In mixed solution of hydrochloric acid and nitric acid, zirconium has no corrosion resistance, as in aqua regia.—JSPS. 14317

6.4 Non-Ferrous Metals and Alloys—Light

6.4.2

Static Strength of Cross-Grain 7075-T6 Aluminum-Alloy Extruded Bar Containing Fatigue Cracks. W. ILLG & A. J. MCEVILY, JR. Langley Aeronaut. Lab. U. S. National Advisory Comm. for Aeronautics, Tech. Note No. 3994, April, 1957, 35 pp.

Cross-grain specimens of 7075-T6 aluminum alloy extrusions were subjected to repeated axial loads until fatigue cracks of various lengths were formed. Residual static strength was then determined by static tests. Small cracks resulted in disproportionately large reductions of static strength. These results showed no significant difference when compared with results for with-grain direction loading. Theoretical predictions indicate that this similarity is not general, but depends upon relative shapes of stress-strain curves. Effects of biaxiality and ductility on notch sensitivity under static loading of sharply notched specimens are discussed in appendixes. Graphs, diagrams of test specimens and grips. —INCO. 14067

6.4.2

The Corrosion Behavior of Super Purity Aluminium. (In German.) E. NACHIGALL. *Aluminium*, **33**, No. 2, 95-100 (1957) Feb.

Results of a series of autoclave tests carried out on super purity aluminum alone and on its alloys with magnesium are reported. The high resistance of these materials to corrosion by moisture, atmospheres and several chemicals is known to decline with increasing temperature, and in distilled water and water vapor at temperatures higher than 100 C combined with elevated pressure, that is, under the same conditions which prevail in some nuclear reactors, they are subject to intercrystalline corrosion and dimensional deformation. The extent of this type of corrosion is an inverse function of the degree of cold reduction and it is said to be relatively low in cast metal. The sensitivity of super purity aluminum to intercrystalline corrosion can be successfully removed by small additions of iron or silicon to the melt, or by the application of inhibitors, such as alkali chromates and alkali silicates to the high temperature aqueous attacking media.—ALL. 13795

6.4.2, 3.7.4, 3.4.9

Experiments in Corrosion Mechanism: Aluminum at High Temperatures. J. E. DRALEY AND W. E. RUTHER. Argonne National Lab. U. S. Atomic Energy Commission Publication, ANL-5658, April, 1957, 27 pp. Available from Office of Technical Services, Washington, D. C.

Hydrogen analyses of corroded 1100 aluminum alloy have indicated an increase in hydrogen content of the metal near the corroding surface. Analyses of M-388 aluminum high temperature alloy have not indicated any such increase. The resistance to disintegrating attack in high temperature water is shown to improve with the amount and dispersion of the cathodic second phase present in the aluminum alloys. The relative abilities of various second phases to protect the alloy against disintegration are in the same order as their abilities to act as effective cathodes at the temperature of testing. Attempts to reduce the corrosion rate of resistant alloys by alloying the aluminum matrix with a solid solution additive have been largely unsuccessful. One alloy, aluminum-1 percent nickel-0.1 percent titanium, gave a lower equilibrium rate but a higher initial intercept. Phosphoric acid at pH 3.5 produces a sizable reduction in the equilibrium corrosion rate of M-388 alloy at 290 C. Tests in superheated steam indicate that cathodic second phases provide corrosion resistance in this medium as they do in water.—NSA. 14411

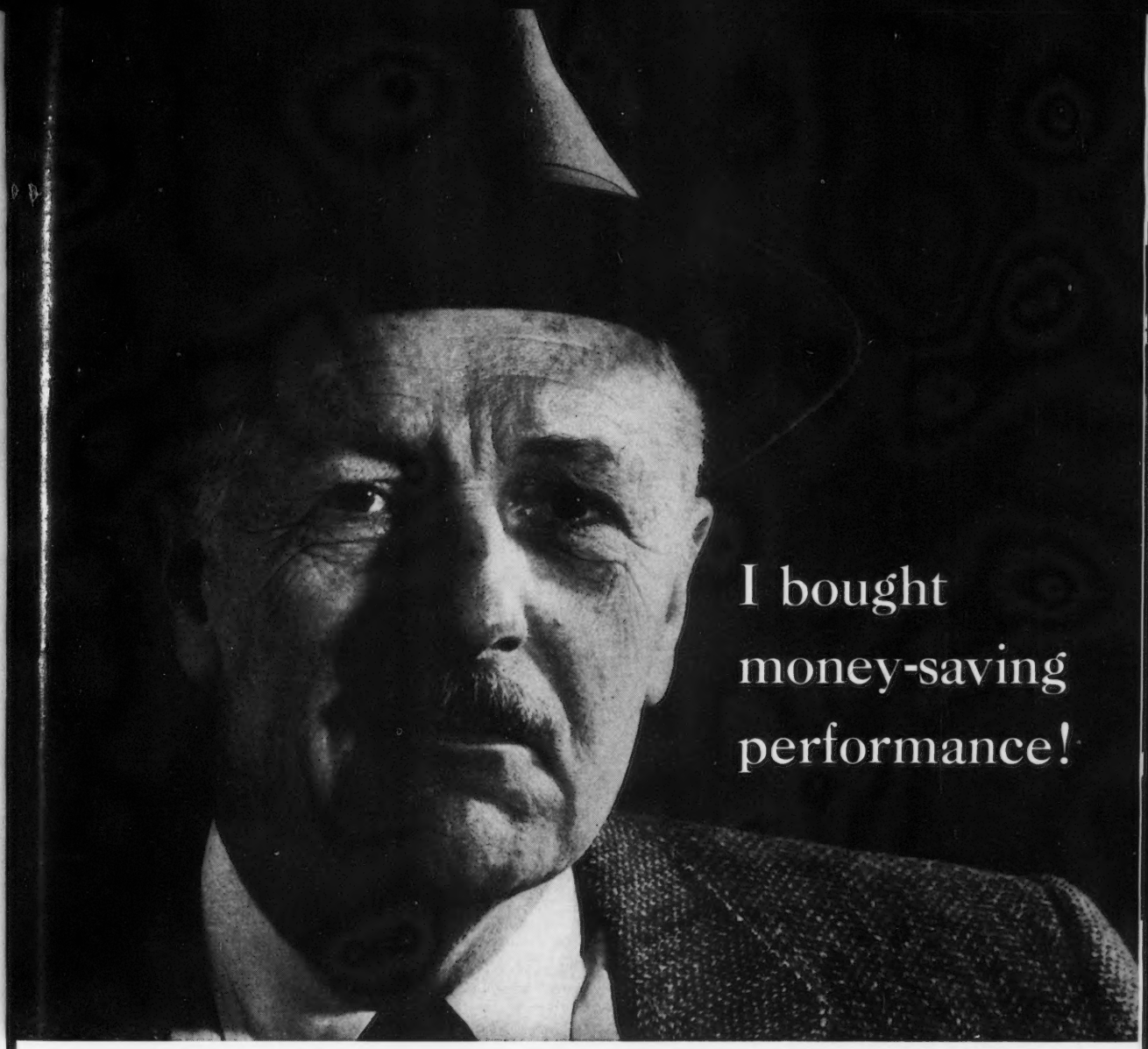
6.4.2

Aluminium Cladding of Buildings. E. H. LAITHWAITE AND E. W. SKERRY. *J. Applied Chem.*, **7**, Pt. 5, 216-231 (1957).

The use of aluminum cladding for buildings to resist atmospheric corrosion is described. Where painting of the aluminum is carried out for protective purposes good performance is obtained with a pretreatment such as degreasing and two-solution pretreatment primer followed by a zinc chromate primer and decorative finish. Red-lead-pigmented primers can be harmful to aluminum.—RPI. 14681

6.4.2, 3.5.3, 4.6.5

Erosion of Aluminum. EDWARD H. HONEYCUTT, JR. E. I. du Pont de Nemours



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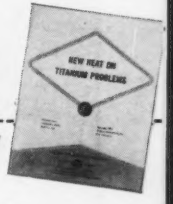

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& Co., Savannah River Laboratory. U. S. Atomic Energy Commission Pubn., DP-214, May, 1957, 16 pp.

Specimens of aluminum were undamaged or eroded only slightly during two months of exposure to deionized water at velocities up to 125 ft. per sec.—BTR. 14692

6.4.2, 3.7.3, 5.9.4

Stress Corrosion Tests on AlZnMgl. Pt. I. Influence of Heat Treatment, Forming, and Anodic Oxidation. (In German.) KURT DIES AND RUTH ZIMMERMANN. *Z. Metallkunde,* **48,** No. 5, 288-296 (1957) May.

Lever test pieces of AlZnMgl in cold-hardened and warm-hardened state were investigated in a 3 percent sodium chloride solution. Influence of heat treatment, deformation and anodic oxidation is discussed. The service life of cold hardened specimens is strongly stress-dependent. 22 references. 14624

6.4.2, 3.7.3

Soldering Aluminum: A Report. J. D. DOWD. *Welding Engr.,* **42,** No. 9, 43-46, 48, 49 (1957) Sept.

Low temperature solders should not be used with aluminum in corrosive applications unless corrosion preventative measures are taken. Small additions of zinc cadmium to these solders improves both soldering characteristics and their resistance to corrosion. Intermediate-temperature solders contain about 30-90 percent zinc, and generally have better wettability, form larger fillets, and give stronger, more corrosion-resistant joints. High-temperature solders contain from 90-100 percent zinc along with small amounts of high-melting temperature metals such as silver, aluminum, copper and nickel; these provide the strongest and most economic solders for aluminum, and have the best corrosion-resistant characteristics. Conditions for satisfactory soldering are given; and organic and chloride-containing reaction fluxes are described and identified with the special application of each. Sections are devoted to solder composition, ultrasonic tinning, salt flux, rinses, corrosion resistance of soldered joints in aluminum, and joint design.—ALL. 14645

6.4.4, 5.4.8

High Temperature Protective Coatings for Magnesium. CLYDE R. FITZGIBBON, EDWARD H. MILLER AND MILTON A. GLASER. U. S. Wright Air Development Center, Materials Laboratory, Technical Report 56-622, April, 1957, 104 pp.

Preferred system is based on an epoxy-polyamide vehicle; it consists of a calcium chromate pigmented primer, containing 35 percent pigment and an aluminized topcoat. Alternate systems are based on a styrenated acrylonitrile modified alkyd-silicone copolymer resin and a mixture of an epoxy ester and a silicone resin.—BTR. 14644

6.4.4

New Magnesium Alloys for High Temperature. T. E. LEONTIS. *Metal Progress,* **72,** No. 2, 97-103 (1957) Aug.

An attempt has been made in this paper to present the basic properties of magnesium-thorium alloys, and to indicate the essential characteristics of some of their commercial and semicommercial alloys. That the use of thorium as an alloying element has markedly increased the temperature range over which magnesium has structurally useful properties has been adequately demonstrated. The wrought magnesium-thorium alloys can be formed by the usual techniques, except that somewhat higher temperatures are required. In addition, they have outstanding welding characteristics and require no subsequent stress relief. They show no evidence of stress-corrosion failure and may be protected against general corrosion by most of the available chemical surface treatment schedules. Wrought magnesium-thorium alloys have been developed more recently than the corresponding casting alloys. Experience is being gained rapidly both in their commercial production and fabrication. Use to date has been confined essentially to experimental-scale applications but their potential as large-scale production materials appears large. (auth.)—ALL. 14671

6.6 Non-Metallic Materials

6.6.5, 6.4.2

Resistance of Aluminium Alloys to Motar-Mixtures. E. FISCHER AND H. VOSSKUHLER. *Aluminium,* **33,** No. 9, 606-612 (1957) Sept.

Since there have been only a few systematic long-term studies on the resistance of aluminum alloys to cement and lime mortars and plaster, a matter of increasing importance because of the expanding use of aluminum in the building industry, the authors conducted detailed studies and have found that unprotected aluminum alloys are indeed sufficiently resistant to such materials, but that nevertheless some protection should be applied. The most effective means of surface protection are lacquers or bituminous paints and greasing. The results of numerous tests are tabulated and graphically represented.—ALL. 14647

6.6.5

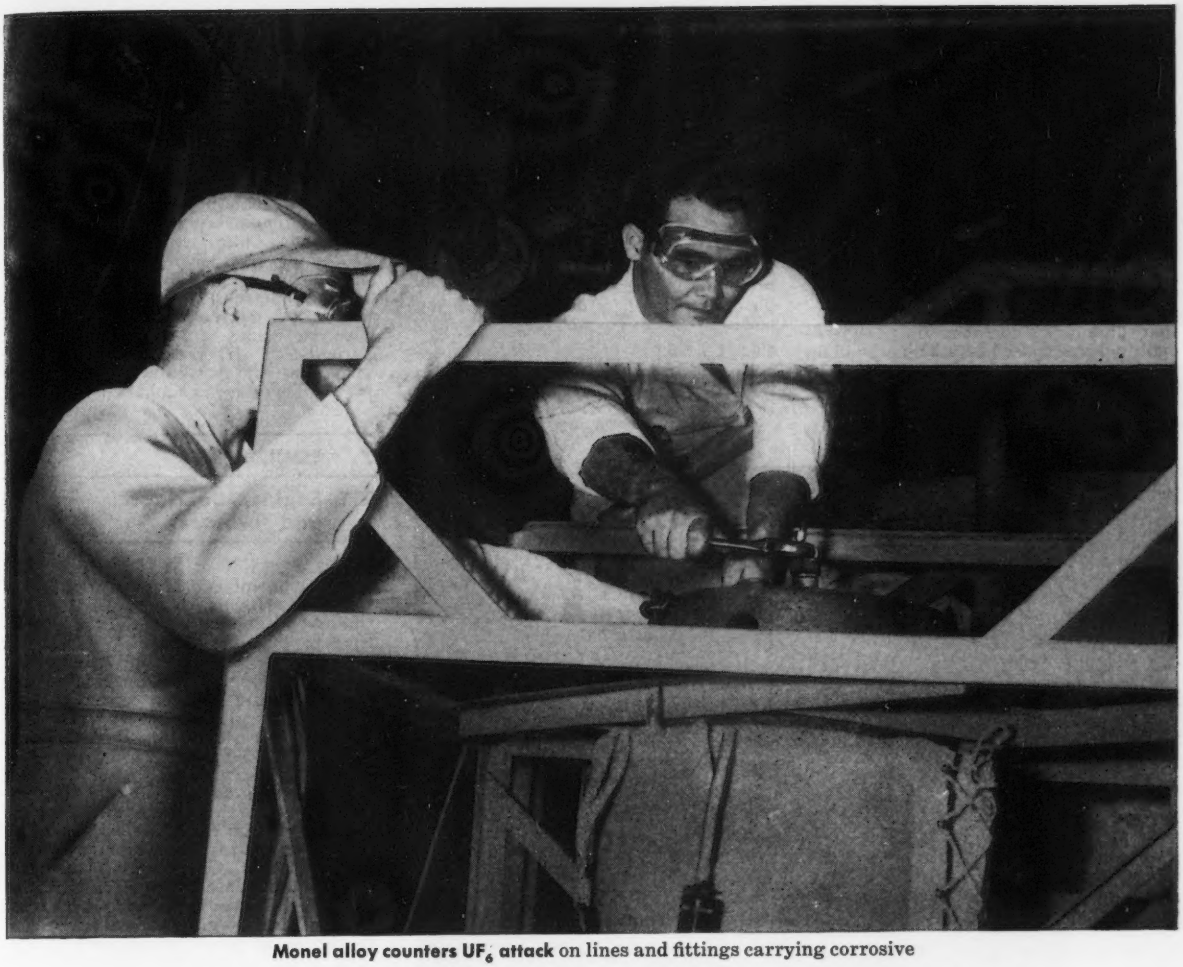
Concrete Deterioration of a Foundation. G. M. IDORN. Acta Polytechnica No. 221, 1957, 48 pp. Acta Polytechnica Publishing Office, Box 5073, Stockholm 5, Sweden.

This monograph describes deterioration of a concrete foundation for a silo in the harbor of Copenhagen. The foundation was poured with concrete of an unknown composition about 50 years ago. Details are given of the ground water composition, soil characteristics, petrographic examination, and physical characteristics of the concrete, badly disintegrated below the ground water level. Carbon dioxide is credited with the major destruction, assisted by sulfates. The monograph concludes that some consideration needs to be given to concrete poured below water levels, with special emphasis on care where aggressive carbon dioxide constituents are present in ground water. Some remedial and preventive suggestions are given. 14697

6.6.5, 6.4.2, 3.6.6

Compatibility of Aluminum with Alkaline Building Products. C. J. WALTON, F. L. MCGEARY AND E. T. ENGLEHART. *Corrosion,* **13,** No. 12, 807t-816t (1957) Dec.

A series of tests is reported on the reaction of aluminum alloys to alkaline building materials under a variety of conditions. After a discussion of the chemistry of reactions between aluminum and alkaline building products, results of a series of laboratory tests are given. Evaluations of effects by visual inspection, galvanic corrosion current measurement, weight loss and microscopic examination were made. These included subjecting alloy 3003-H14 to a



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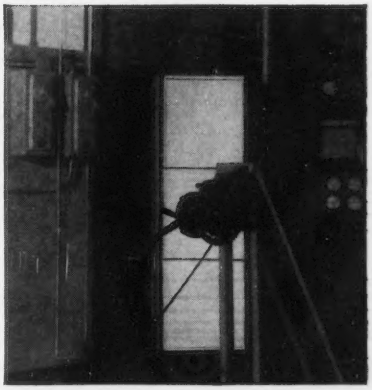

Inconel alloy reduces oxidation damage to batch trays and fixtures in 1500°F converting furnaces

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series of exposures to asbestos cement products, insulation materials, alkaline flooring materials, mortar and concrete cured dry and wet, and assessing the effects of galvanic couples to steel in varying ratios up to 1:12, and at spacings from 4 inches to ⅛-inch; effects of chlorides, curing conditions, and others. Mechanism of corrosion in mortar and concrete is examined and a study is made of polarization characteristics of an aluminum-to-steel couple in mortar. Stray currents are cited to explain infrequent cases of severe corrosive attack of aluminum in concrete. Tests reveal, and related service experiences confirm, that aluminum corrodes only superficially when exposed to alkaline building products and that this corrosion is self-limiting in nature. Protective measures may be needed in cases involving dissimilar metals and differential aeration effects in the presence of relatively high chlorides. 14445

6.6.6, 6.6.5

Corrosion-Resistant Floors. Pt. II. V. EVANS. *Corrosion Technology,* **4,** No. 4, 120-124 (1957) April.

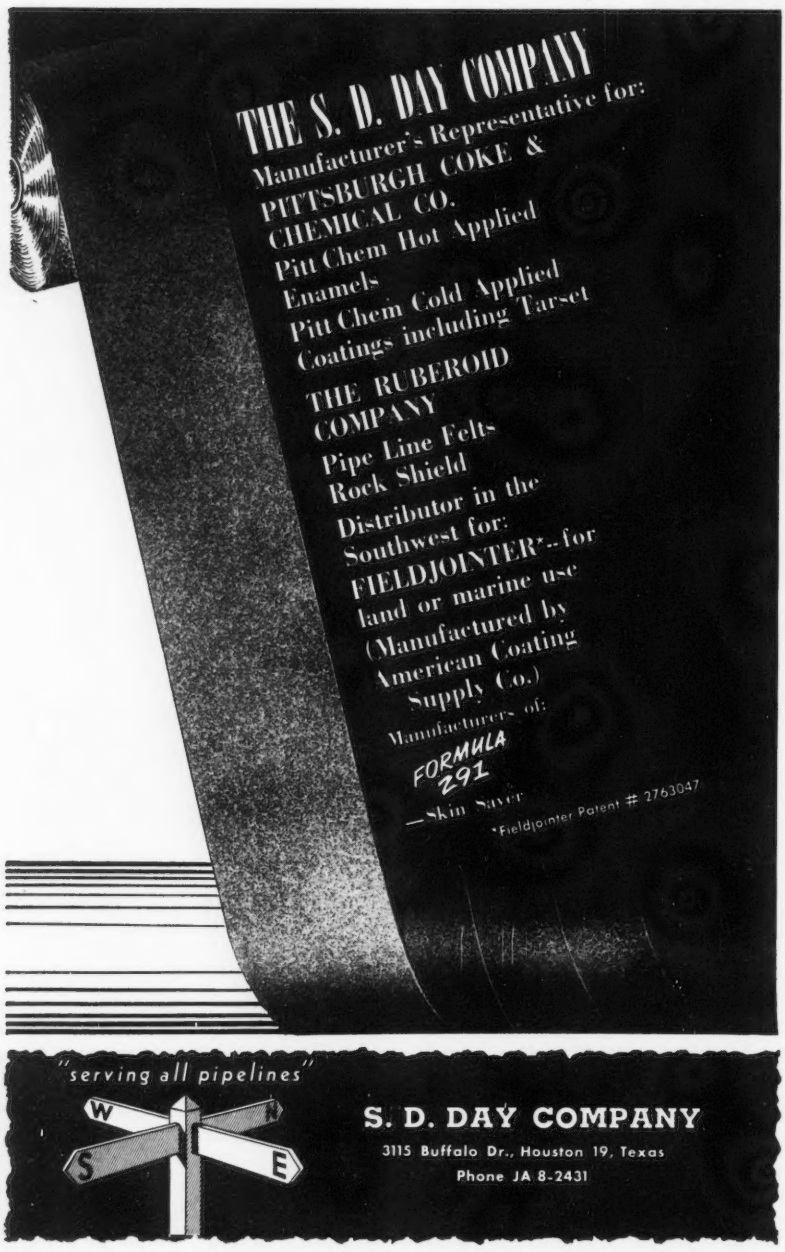
The author describes the properties of various types of cement, bricks and tiles suitable for floors. In pickling plants silicate cements or carbon bricks are suitable and in plating shops good performances have been obtained with bricks set in synthetic resin of the furane phenolic or cashew nutshell liquid type. —ZDA. 14727

6.6.8, 1.6, 6.6.7

Engineering Properties and Applications of Plastics. GILBERT FORD KINNEY. Book, August 7, 1957, 278 pp. John Wiley & Sons, Inc., 440 Fourth Ave., New York 16, N. Y.

A comprehensive treatise on the common plastic materials of construction. Chapters are given on polyethylene, polyvinyl chloride, polystyrene, acrylics, other vinyl types, cellulosics, phenolics, amino plastics, polyesters, polyamides and epoxies, silicones, rubbers.

An explanation is given of molding methods, engineering properties, thermal properties, optical properties, electrical properties. Extensive data are given on plastics chemistry with diagrams of typical molecules, potential energy, polymerization mechanics, aromatic hydrocarbons, acids, esters, anhydrides and particle-size distribution. Tables of properties of representative plastics are given. There is an alphabetical subject index. 14282



7. EQUIPMENT

7.1 Engines, Bearings and Turbines

7.1, 6.2.2, 8.9.5

Development and Uses of Spheroidal Graphite (Nodular) Cast Iron for Marine Applications, with Special Reference to Diesel Engines. A. G ARNOLD AND B. TODD. Paper before British Cast Iron Res. Assoc. Conf. on Engineering Properties and Uses of Iron Castings, London, Nov. 1956. *J. Research and Development, Brit. Cast Iron Res. Assoc.,* **6,** No. 11, 588-598; disc., 598-599 (1957) April.

Continued improvement of Diesel engine and more exacting specifications for construction materials lead to adoption of modular cast iron for Diesel engine pistons. Optimum properties of piston materials are given, and on this basis high duty nickel-chromium cast iron, spheroidal graphite cast iron and 13 chromium steel are compared. Failures, their causes and improvements effected in use of spheroidal graphite irons for Diesel pistons are considered. Effect of piston operating temperatures is studied. Future developments are discussed. Further applications of spheroidal graphite cast iron in marine engineering are discussed; these include Diesel engine liners, ship side-valves, and Diesel engine bedplates. Photomicrographs, tables.—INCO. 14875

7.4 Heat Exchangers

7.4.1, 3.5.8, 6.2.5

Stress-Corrosion Cracking of Austenitic Stainless Steels in Chemical Plant Equipment. WILLIAM C. RION, JR. *Ind. and Eng. Chem.,* **49,** Pt. 1, 73A + 3 pp. (1957) March.

These case histories of condensers and heat exchangers, cooling coils and contact with wet thermal insulation may aid in solving stress-corrosion cracking failures.—BTR. 14174

7.4.2

Low-Finned Exchanger Tubing. R. G. NEWELL. *Petroleum Processing,* **12,** No. 4, 77-81 (1957) April.

Discussion of method for designing units for forced convection heat transfer without change of phase. Results of fouling tests in low-finned tubes in a gasoline condenser are given. In these tests, No. 5 fuel oil was continuously circulated through heat exchanger bundles for four weeks. During test, oil was stored in an open tank and oxidation

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and evaporation changed its properties considerably. Similar runs were made on bundles of identical proportions of low-finned tubing and bare tubing. At end of tests, fouling factors of both bundles were below TEMA Standards and finned tube followed a pattern of change of fouling factor similar to that of bare tube. Photos, graphs.—INCO. 14735

7.5 Containers

7.5.2

Containers for Automotive Products. R. G. NUGENT AND G. E. CURTIS. Paper before Chemical Specialties Mfrs.' Assn. 43rd Ann. Mtg., Washington, D. C. December 5, 1956. *Soap & Chemical Specialties*, **33**, Nos. 2, 3, 129, 131, 133, 135, 200; 121, 123, 125 (1957) Feb., March.

Discusses test procedures involved in determining fitness of metal container for automotive and other chemical specialty products. Test variables include container materials (plate, enamels, cap liners, and sealing compounds), storage temperatures, and test duration. Plain and enameled cans and seam areas are examined for corrosion after storage tests. Metal strip specimens are used for preliminary tests.—INCO. 13801

7.6 Unit Process Equipment

7.6.3, 4.3.4

Withstands Aggressive Corrosion and Abrasion. W. V. V. BACON AND G. WEYERMULLER. *Chem. Processing*, **20**, No. 7, 44-45 (1957) July.

Corrosion caused by caustic and abrasion from suspended silica limited life of large steel autoclaves to about 3 years at Westvaco Chlor-Alkali Div. of Food Machinery. Autoclaves were utilized in production of Magnesol (magnesium silicate) which is an industrial absorbent powder. In manufacture of Magnesol, sodium silicate of desired alkalinity is produced by batch digestion of an excess of pure silica flour in 50 percent liquid caustic under pressure at 350 F. Use of 1¼ in. carbon steel for inner shell of jacketed vessels in which foregoing reaction takes place resulted in excessive maintenance and replacement costs. Corrosion tests indicated a probable minimum life of 10 years for Monel-clad vessel having a minimum clad metal thickness of 0.125 in. so an autoclave with all surfaces in contact with reaction protected by Monel was constructed and placed in service in December 1950. Monel-clad vessels are still in excellent condition with up to 6 years of nearly continuous service. Use of this type of construction has resulted in a considerable saving in maintenance and replacement costs. Photos.—INCO. 14728

7.7 Electrical—Telephone and Radio

7.7, 6.3.8, 3.3.4

Corrosion of Lead Cases of Underground Electric Cables. (In French.) J.-C. SENEZ AND F. PICHINOTY. *Corrosion et Anticorrosion*, **5**, 203-209 (1957) July-Aug.

This corrosion is characterized by the formation of $2PbCO_3 \cdot Pb(OH)_2$ and $PbCO_3$ in variable proportions and is frequently due to attack on the lead by volatile acids present in the form of esters in the raw jute. These esters are hydrolyzed in the cable by pectinolytic bacteria.—BTR. 14788

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THE PROBLEM: To protect the steel rake arms and influent wells in three 200′ diameter presediment basins.

THE ANSWER: Duriron impressed current anodes! Strings of Duriron 1¼″ dia. x 9″ long anodes were 1) extended along both sides of the rake arms, 2) hung vertically to protect the lower section influent wells and center structures, and 3) suspended horizontally on a 16½′ radius at a depth four feet below the water level.

These systems have been in operation for 18 months (220,000 ampere hours per basin). The structures are thoroughly protected, and the consumption rate of the anodes is approximately 0.25 lbs./amp. yr. The life expectancy of the systems is 15-20 years.

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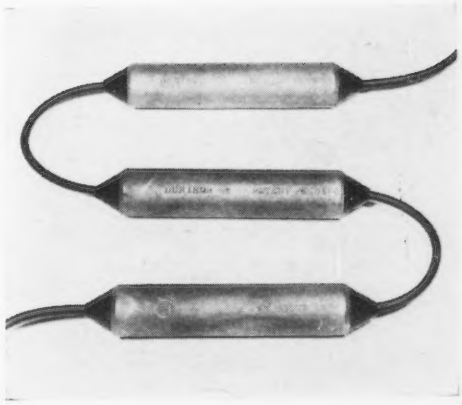

Duriron anodes are available in a variety of shapes and sizes for applications in fresh water, ground bed, and salt water services. For complete details, see your cathodic protection specialist or write The Duriron Company, Inc.; Dept. CP; P. O. Box 1019; Dayton, Ohio.

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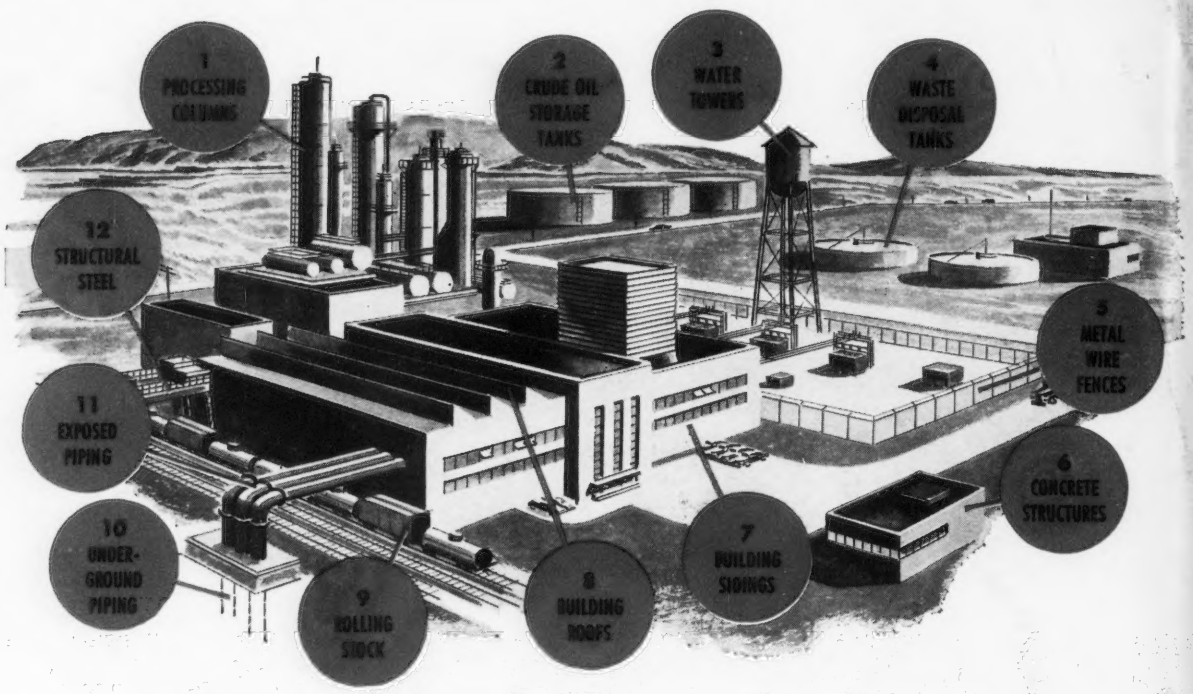

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4. Waste Disposal Tanks—Use acid and alkali-resisting *Tarset* or tough, heavy-bodied PITT CHEM *101.*

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